NASA-CR-145370

M79-12527

DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS CORPORATION

108698

NASA CR-145370

CONTRACT NAS1-15069

ADVANCED COMPOSITE AILERON FOR L-1011 TRANSPORT AIRCRAFT

DRL 006

TASK I – FINAL REPORT

This report is for the period 19 September 1977 through 24 March 1978

Lockheed Corporation
Lockheed-California Company
Post Office Box 551
Burbank, California 91520

Approved By:
F. C. English
Program Manager

July 1978

Prepared for: National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

FEDD DOCUMENT

Note that this document bears the label "FEDD," an acronym for "FOR EARLY DOMESTIC DISSEMINATION." The FEDD label is affixed to documents that may contain information having high commercial potential.

The FEDD concept was developed as a result of the desire to maintain U.S. leadership in world trade markets and encourage a favorable balance of trade. Since the availability of tax-supported U.S. technology to foreign business interests could represent an unearned benefit, research results that may have high commercial potential are being distributed to U.S. industry in advance of general release.

The recipient of this report must treat the information it contains according to the conditions of the FEDD label on the front cover.

FOREWORD

This report was prepared by the Lockheed-California Company, Lockheed Corporation, Burbank, California, under contract NAS1-15069. It is the final report of Task I, Engineering Development, covering work completed between 19 September 1977 and 24 March 1978. The program is sponsored by the National Aeronautics and Space Administration (NASA), Langley Research Center. The Program Manager for Lockheed is Mr. Fred C. English and the Project Manager for NASA, Langley is Mr. Louis F. Vosteen. The Technical Representative for NASA, Langley is Mr. Herman L. Bohon.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

PAGE MISSING FROM AVAILABLE VERSION

LIST OF TABLES

ADVANCED COMPOSITE AILERON
FOR L-1011 TRANSPORT AIRCRAFT

C. F. Griffin, L. D. Fogg, R. L. Stone, E. G. Dunning

Lockheed-California Company

SUMMARY

The activities documented in this report are associated with Task I of the Advanced Composite Aileron (ACA) program. These activities include: design assessment, material evaluation, and program plans.

Structural design and maintainability criteria were established. Using these documents as a guideline, a variety of configurations and materials were evaluated for each of the major subcomponents. From this array of subcomponent designs, several aileron assemblies were formulated and analyzed. The selected design is a multirib configuration with sheet skin covers mechanically fastened to channel section ribs and spars.

Qualitative analysis of currently available composite material systems led to the selection of three candidate materials. Comparative structural tests were conducted on the candidate materials to measure the effects of environment and impact damage on mechanical property retention. In addition, each system was evaluated for producibility characteristics. From these tests, Thornel 300/5208 unidirectional tape was selected for the front spar and covers, and Thornel 300 fabric/5208 was chosen for the ribs.

Program plans were established for materials evaluation and selection, defining the ancillary tests required for materials and concept verification, defining the approach to be followed in satisfying the Federal Aviation Administration (FAA) requirements for certification, and establishing the procedures for preparation and implementation of a structural integrity program.

INTRODUCTION

The broad objective of NASA's Aircraft Energy Efficiency (ACEE) Composite Structures Program is to accelerate the use of composite materials in aircraft structures by developing technology for early introduction of structures made of these materials into commercial transport aircraft. This program, one of several which are collectively aimed toward accomplishing this broad objective, has the specific goal to demonstrate the weight and cost-saving potential of secondary structures constructed of advanced composite materials. The secondary structure selected for the program is the inboard aileron of the Lockheed L-1011 transport aircraft.

The scope of this program is to design, fabricate, qualify, and certificate a composite inboard aileron; to test selected subcomponents to verify the design; to fabricate and test two ground test articles; to fabricate and install ten shipsets of inboard ailerons; and to gather flight service data on the ten shipsets of composite ailerons.

The Lockheed-California Company is teamed with Avco Aerostructures Division of Avco Corporation. Lockheed will design the aileron, conduct the materials, concept verification, and ground tests, and evaluate in-flight service experience. Avco will develop manufacturing processes, fabricate test specimens, and fabricate the ground test and flight articles.

As shown on the master schedule, figure 1, the program is being conducted in six nonsequential tasks. Task I, Engineering Development, and Task II, Design and Analysis, are the portions of the program wherein the composite aileron design will be formulated and subcomponents fabricated and tested to verify design concepts and fabrication procedures. During Task III, Manufacturing Development, and Task IV, Ground Test and Flight Checkout, production quality manufacturing tools will be constructed, and two full-scale ailerons will be fabricated and tested. A production run of ten shipsets will be fabricated during Task V, Aileron Manufacture, to provide manufacturing and cost information. In Task VI, Flight Service, inspection and maintenance data will be gathered on the ten shipsets of ailerons to assess their potential for economical operation in routine service. The work performed during this program is intended to provide the data required to progress toward a production commitment.

This report describes work accomplished during Task I. Activities of Task I are reported under the following headings: Design Assessment and Materials Evaluation.

SYMBOLS

Symbol	Definition	Symbol	Definition
b	Panel width	MR	Manufacturing review
CDR	Critical design review	Nxy_{cr}	Shear buckling load
DR	Design review	t	Panel thickness
FRR	Flight readiness review	t_c	Core thickness
F_{scr}	Shear buckling stress	t_s	Skin thickness
f_s	Applied shear stress	ρ	Density
GTR	Ground test review	ρ_c	Core density

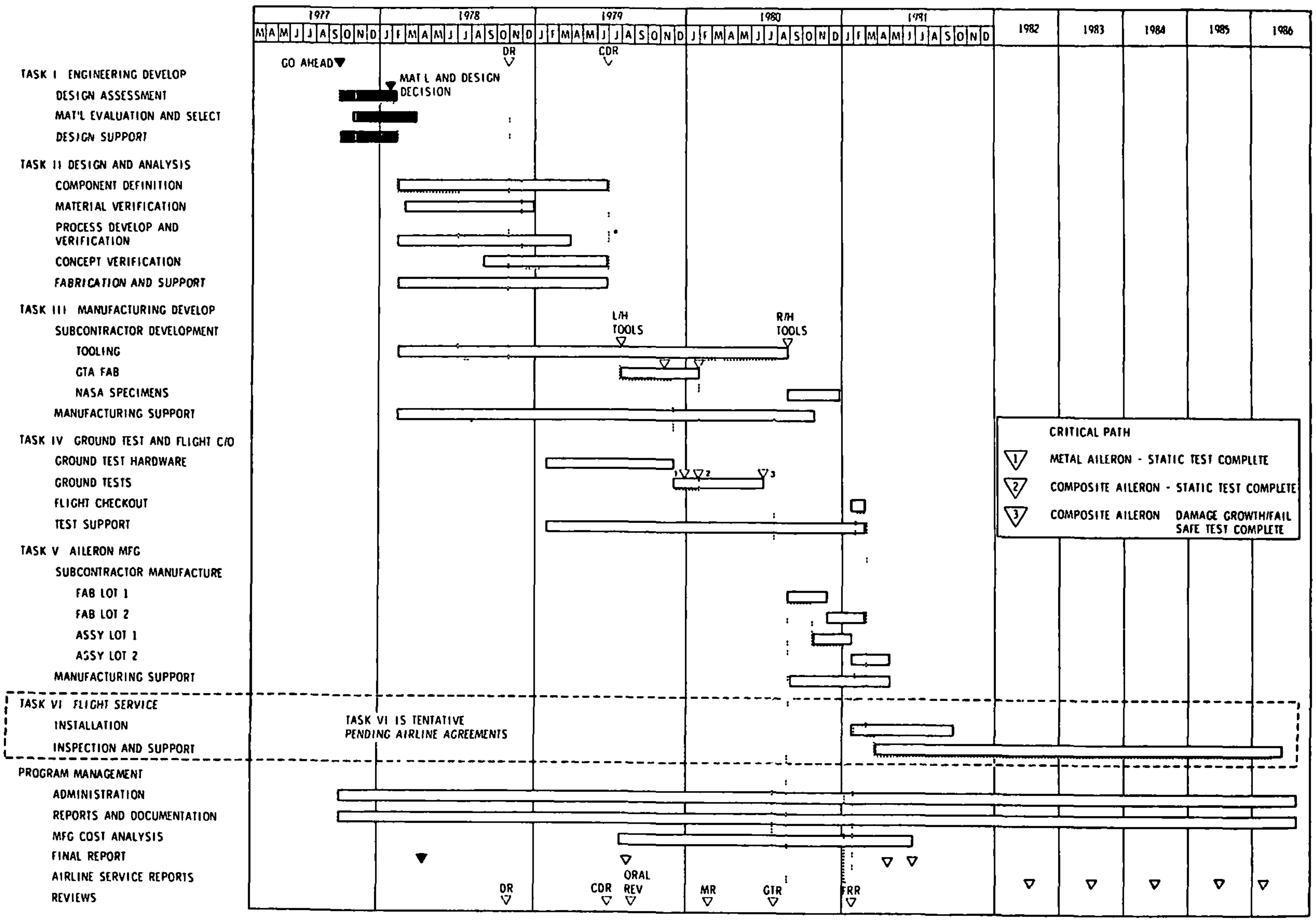


Figure 1. - Advanced composite aileron - program master schedule.

MEASUREMENT VALUES

All measurement values in this technical report are expressed in the International System of Units and customary units. Customary units were used for the principal measurements and calculations.

DESIGN ASSESSMENT

Aileron General Description

The inboard aileron is located on the wing trailing edge between the outboard and inboard trailing edge flaps and is directly behind the engine, as shown in figure 2. It is supported from the wing at two hinge points and is actuated by three hydraulic actuators. Basic dimensions of the inboard aileron are shown in figure 3. It is basically a wedge-shaped, one-cell box, thinning slightly from root to tip. The planform is trapezoidal, with parallel leading and trailing edges.

Structural Configuration - Metal Aileron

The inboard aileron is a single-cell box beam with added trailing-edge wedge, leading-edge shrouds, and end fairings. An illustration of the current aluminum inboard aileron is shown in figure 4.

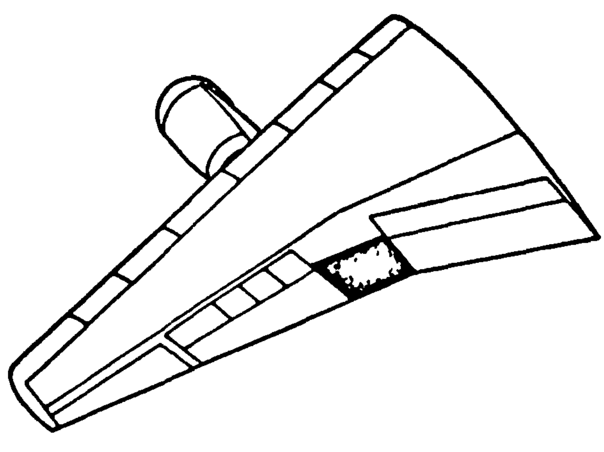


Figure 2. - Inboard aileron location.

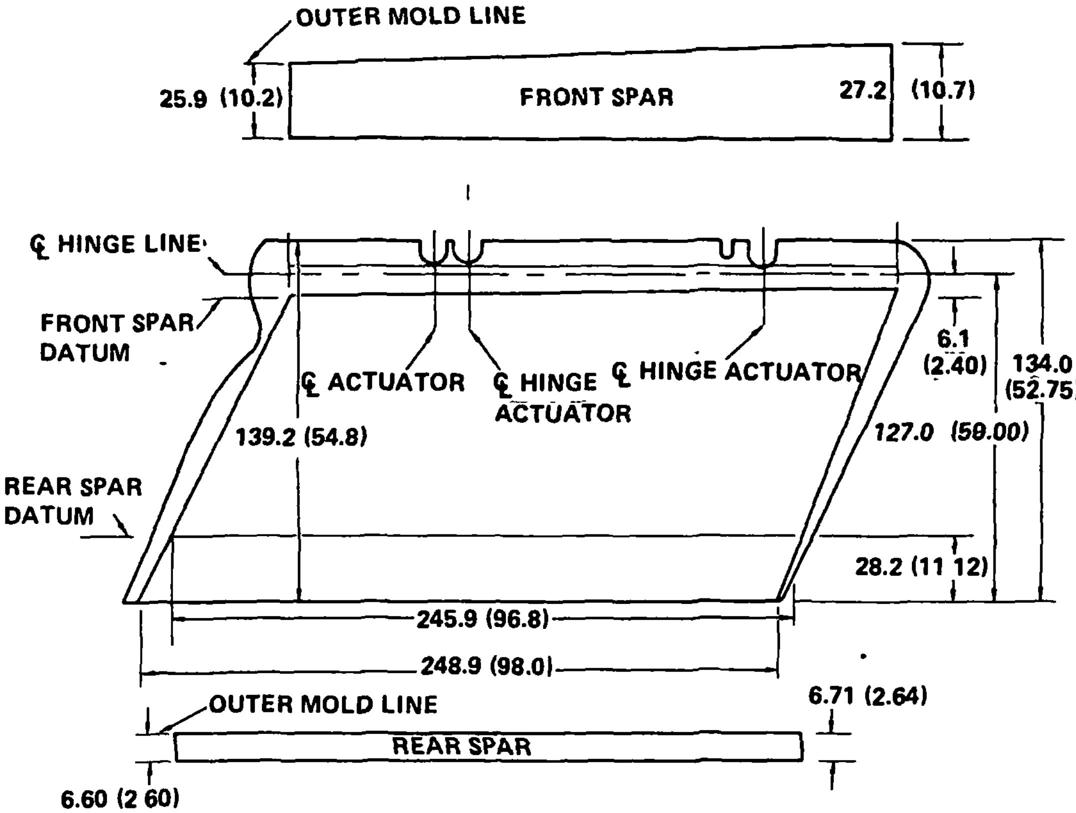


Figure 3. - Inboard aileron dimensions
(All dimensions shown in cm (in.)).

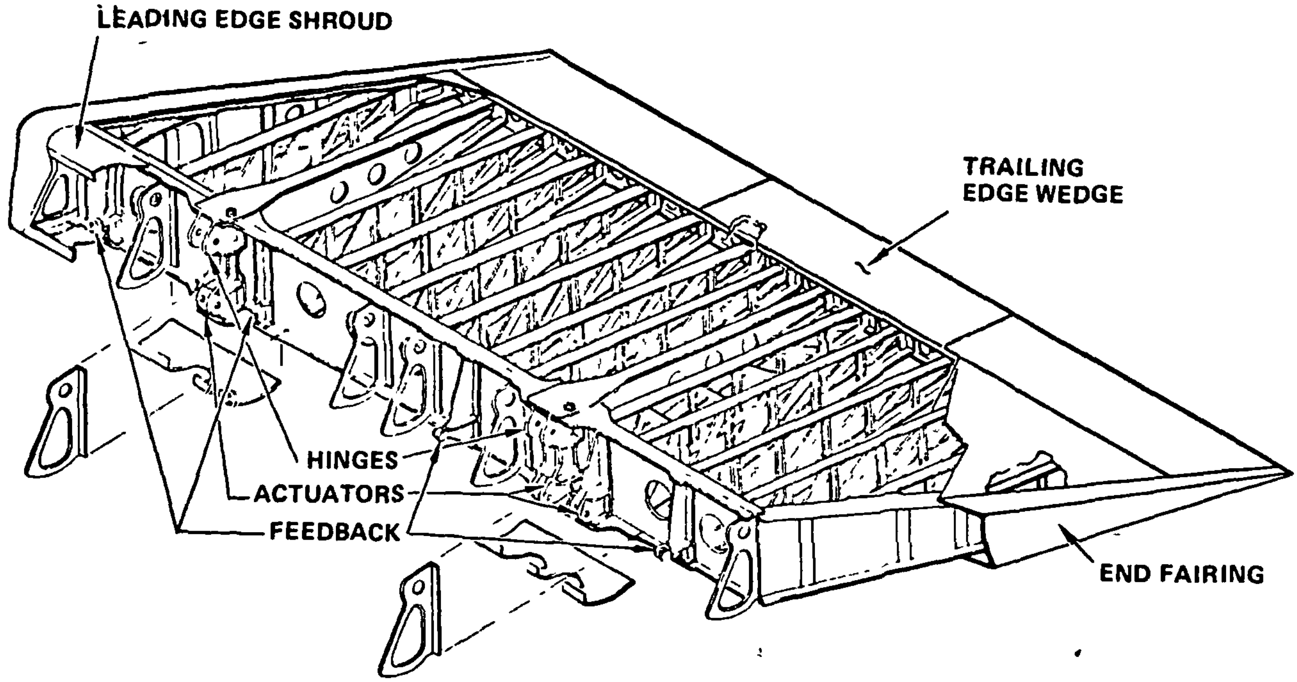


Figure 4. - Current aluminum aileron.

The box consists of a front beam, rear beam, and upper and lower skins, joined by hinge ribs and airload ribs. The front beam consists of a web with lightening holes and extruded caps. Attached to the web are formers supporting the shrouds, which consists of two aluminum clad sheets bonded together.

The rear beam is an I section extrusion with lightening holes in the web. Upper and lower skins are clad aluminum sheets with bonded doublers and are attached to the rib caps with rivets on the upper surface and screws on the lower surface.

Joining the front and rear beams are ribs at about 17.8 cm (7 in.) pitch, most of which are airload ribs. These are of channel extrusion truss construction. The two main actuator ribs are of cap and corrugated web construction, with fittings at the front beam to accommodate hinge and actuator loads, and with titanium straps splicing the upper rib caps and skin to the front beam cap.

The trailing-edge wedge is a sandwich construction and is attached to the rear beam in three discontinuous sections with screws. The end fairings are of beaded fiberglass construction, attached to the close-out rib caps with screws.

The aileron support fittings are aluminum two-piece forgings, joined by Hi-Tigue fasteners. The hinge bearing housing are separate split fittings bolted to the aileron support fittings.

ACA Design Criteria

The design philosophy and objectives include the following:

- The composite aileron will be a direct replacement for the metal aileron without equipment modification, no operating restrictions, and no decrease in performance.

- At least 40 percent by weight will be fabricated from composite materials. Metal will be used only where nonmetallics might be inefficient. A weight savings of at least 20 percent will be demonstrated (relative to the current metal aileron weight).

- Materials and fabrication processes to be used are state of the art. Materials will be selected to satisfy structural and environmental requirements and allow low-cost processing.

- Static strengths of laminates will be predicted per lamination theory with a maximum strain theory of failure for uniaxial loading conditions. Factors for notched and environmental conditions will be developed empirically.

- Initial buckling stress of secondarily bonded structures subjected to compression or shear stress will be equal to or greater than ultimate load stress.

Aileron loads are related to hinge moment capabilities. Deflection of an aileron causes an airload hinge moment which is reacted by the actuators. Larger deflections give larger airloads until the maximum hinge moment produced by the actuators is reached. Included in the basic loads criteria for the ACA are several conditions to account for loads - moisture - temperature interactions. In addition to airloads, the aileron must be designed to withstand acoustic spectrum levels of 135 db/Hz.

Mass distribution and torsional stiffness of the aileron will be designed to preclude self-induced vibrations. The criterion for the inboard aileron torsional stiffness is 8.61×10^5 Pa-m^2 (300×10^6 lb-in^2).

Tolerance of the composite aileron to foreign object damage will be considered. A detailed analysis of the hazard environment was conducted, including a survey of airline service experience on the inboard aileron. Based on this analysis, it was concluded that hail impact on the aileron when the airplane is on the ground posed the greatest threat. A probability analysis, which considered airline route structure and geophysical data, lead to the establishment of the following criteria: The inboard aileron must be capable of withstanding impacts from 1.78 cm (0.70 in.) diameter hailstones at terminal velocity (this equates to an impact energy of 0.588J (0.412 ft-lb) with no loss of strength.

The aileron structure will be designed to be fail safe for limit flight loads in accordance with FAR 25 fail-safe requirements. The aileron will also be designed not to separate from the airplane after any one of several failures or jams premised in FAA requirements.

The maintainability/reliability design guidelines which have been established for the composite aileron are summarized below:

- The ACA assembly must be interchangeable in form, fit, and function with the existing metal aileron.
- Front spar access holes shall be equivalent to those in the existing metal aileron.
- External surfaces must be provided with lightning strike protection, with adequate electrical bonding to aircraft structure to protect against Zone 2 or swept-stroke lightning.
- The lower surface must be removable and replaceable. This panel must be interchangeable with one of like design.
- The trailing-edge, leading-edge shroud, and end fairings must be interchangeable with the metal aileron.
- Minimum allowable flange thickness in countersunk holes must be 1.5 times the depth of the countersunk profile.

- Skin panels should be joined to the ribs and spars with metal fasteners.

- The maximum depth of honeycomb core structure should be limited to 7.62 cm (3.00 in.).

- Minor damage to skin panels shall be repairable in situ.

Common Structure

Certain subassemblies used on the aluminum aileron will also be used for the composite aileron. These include: leading-edge shrouds, end fairings, trailing-edge wedge, shroud supports, feedback fittings, and hinge/actuator fittings. These subassemblies were not redesigned because analysis indicated it would not be cost effective and no significant weight savings could be achieved.

Alternate Concepts

The results of Contract NAS1-12939, "Design of Advanced Composite Ailerons on Transport Aircraft" as published in NASA CR-132637 (Reference 1), NASA CR-132638 (Reference 2), and NASA CR-132639 (Reference 3) were reviewed, and the various alternate concepts proposed in these reports were reevaluated in view of recently improved technology. In addition several new concepts were investigated.

Alternate concepts were designed and evaluated for covers, front and rear spars, main and intermediate ribs, and rib backup fittings. Selections were made for aileron assemblies and the assemblies were evaluated for the final concept selection.

The quantitative factors evaluated for each design were weight and cost. Premises used to conduct the cost analysis are shown in table 1. Qualitative factors included: tooling and manufacturing processes, inspectability, impact resistance, environmental sensitivity, maintainability, and repairability.

<u>Covers</u>. - Ten concepts were subjected to preliminary design analysis and evaluation. Each included end ribs and three hinge/actuator ribs. Intermediate ribs are required to stabilize the cover for some concepts. Fifty percent of the weight of the ribs was included in the cover weight to afford comparisons of concepts.

One of the cover concepts investigated is a thin sandwich construction which has been developed at Lockheed under a company funded Independent Research and Development program. Figures 5 and 6 show why this concept is being considered for the ACA. Stability considerations for aircraft elements frequently

TABLE 1. - PREMISES FOR COST ANALYSIS

Estimates of Production Labor Costs based on the following:	
• Recurring costs with amortized tooling costs added	
• Estimated labor rates for 1983	
• Cumulative average for a design quantity of 100 aircraft	
• Setup for labor amortized over a lot quantity of 12 aircraft	
Estimates of Material Costs based on the following:	
• 1977 dollars projected to 1983 costs	
• Graphite tape	@ $ 44/kg ($20/lb)
• Graphite fabric - single ply	@ 55/kg (25/lb)
• Graphite preply (wide broadgoods)	@ 68/kg (31/lb)
• Graphite preply (narrow strips)	@ 86/kg (39/lb)
• Kevlar 49	@ 35/kg (16/lb)
• Nomex H/C	@ 55/kg (25/lb)
• Syntactic epoxy	@ 88/kg (40/lb)
• Adhesive film	@ 112/kg (51/lb)
• Added to the above would be an estimated usage factor of 25 percent.	

require a laminate thickness greater than that necessary to meet strength requirements. For these cases a lightweight core material was developed which is compatible with the processing procedures of solid laminates. This core material, syntactic epoxy, is a film adhesive filled with hollow glass microspheres. The density of the syntactic epoxy is approximately 0.446 kg/m^3 (0.025 lb/in^3). This core material is normally used for core thicknesses less than 0.254 cm (0.10 in.), which is below the minimum thickness honeycomb core can be sliced and used.

A comparison of the structural efficiency of a shear-resistant graphite/epoxy panel with an aluminum panel which is allowed to buckle at loads below ultimate (see figure 5) indicates that the composite panel would be heavier. However, when a core of syntactic epoxy is used to create a thin sandwich with graphite/epoxy facesheets, this composite construction is more efficient than the aluminum design which is allowed to buckle. Figure 6 illustrates the efficiency of a graphite/epoxy sandwich configuration with syntactic core compared to solid graphite/epoxy laminates for use as a shear panel.

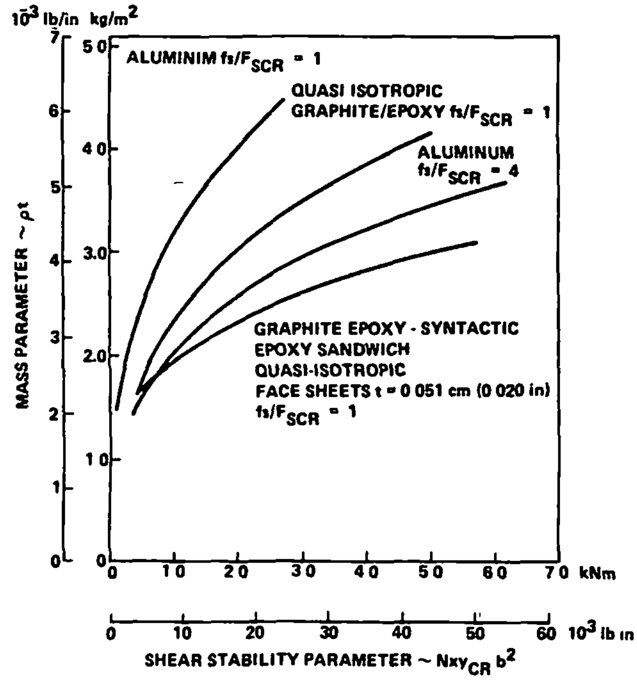


Figure 5. - Shear stability efficiency comparison of aluminum, graphite, and graphite syntactic panels.

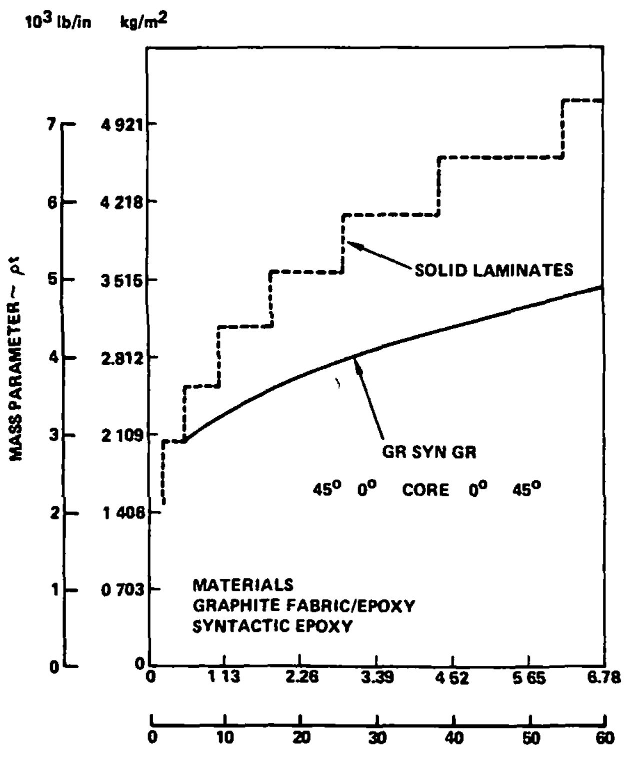


Figure 6. - Shear stability efficiency comparison of solid laminates and syntactic sandwiches.

The covers were designed based on the following criteria: a minimum required shear stiffness, no shear buckling at ultimate load, and an external pressure with surface deflection limits. The design shear flow distribution, taken from the metal aileron internal loads analysis, is shown in figure 7. The external pressure distribution is triangularly distributed, from 35.4 kPa (5.13 psi) at the front spar to 0 at the trailing edge. Typical design concepts evaluated for the covers are shown in figures 8 through 10. The evaluation matrix for the covers is shown in table 2.

An evaluation of the data in table 2 led to the following selections for further evaluation:

- Sheet skin - Concept 3, graphite tape and syntactic core with five intermediate ribs.
- Sheet skin - Concept 10, graphite fabric and syntactic core with five intermediate ribs.
- Honeycomb Sandwich - Concept 5, Kevlar 49 fabric on Nomex honeycomb.

Based upon the relatively higher weights and costs, no further consideration was given to the stiffened skin design.

Intermediate ribs. - The intermediate ribs stabilize the covers and react air pressure loads. Typical geometry and loads of an intermediate rib are shown in figure 11. Each intermediate rib design evaluated had a channel cross section with flanged lightening holes in the web. A typical example is shown in figure 12. Consideration was given to a beaded web design, however, the inability to determine an economically feasible manufacturing method for this configuration led to its deletion.

Following preliminary design to satisfy the structural requirements, each concept was evaluated for cost, weight, and the qualitative factors described previously. The results of these evaluations are shown in table 3. Based on these data, two designs, the graphite fabric design concept #2, and the graphite tape (0.019 cm (7.5 mils)/ply) design concept #6, were selected for further evaluation.

Main ribs. - The three main ribs distribute the actuator and hinge loads into the aileron torque box. The rib at inboard aileron station (I.A.S.) 107.098 transmits an actuator load. The two remaining actuator ribs at I.A.S. 57.087 and I.A.S. 102.698 accommodate both hinge and actuator loads. Each of these main ribs is connected to a hinge/actuator fitting through the spar web. To facilitate transmission of the concentrated loads a rib backup fitting is used. This fitting attaches to the web and caps of the rib and the aft face of the spar web.

The ultimate design loads for the main rib at I.A.S. 102.7 included a rib cap load of 29 157N (6555 lb) and a shear flow of 14 010 N/m (80 lb/in.) just aft of the rib attach fitting at the front spar. The typical main rib design

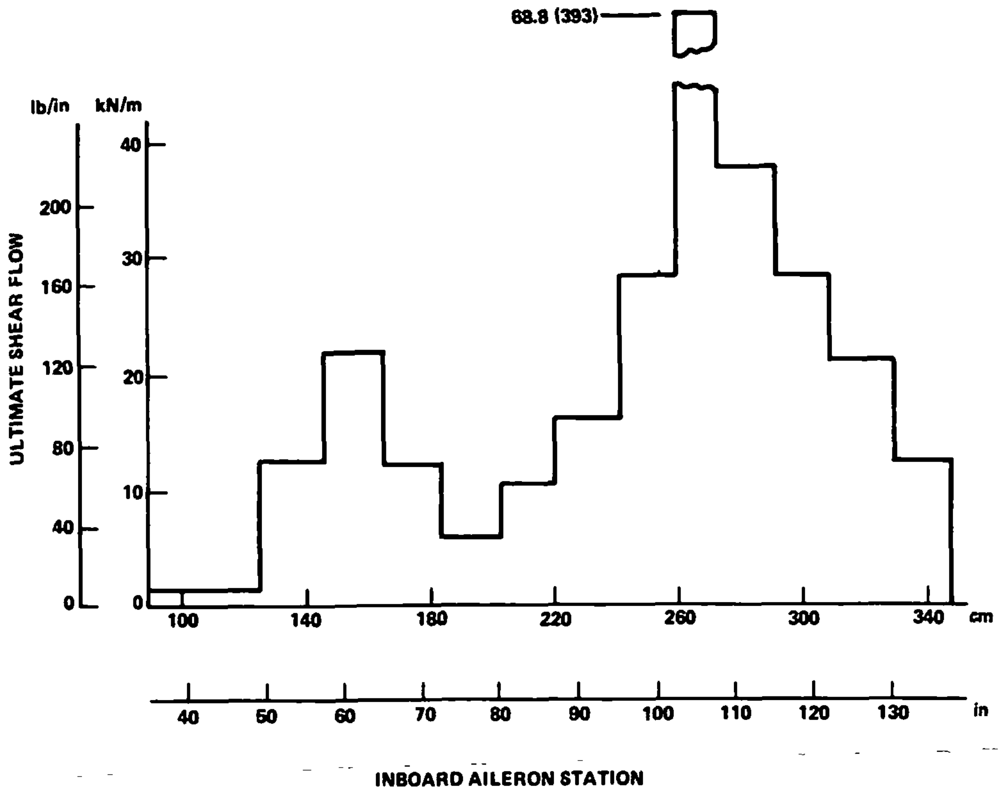


Figure 7. - Envelope of surface shear flows - metal aileron.

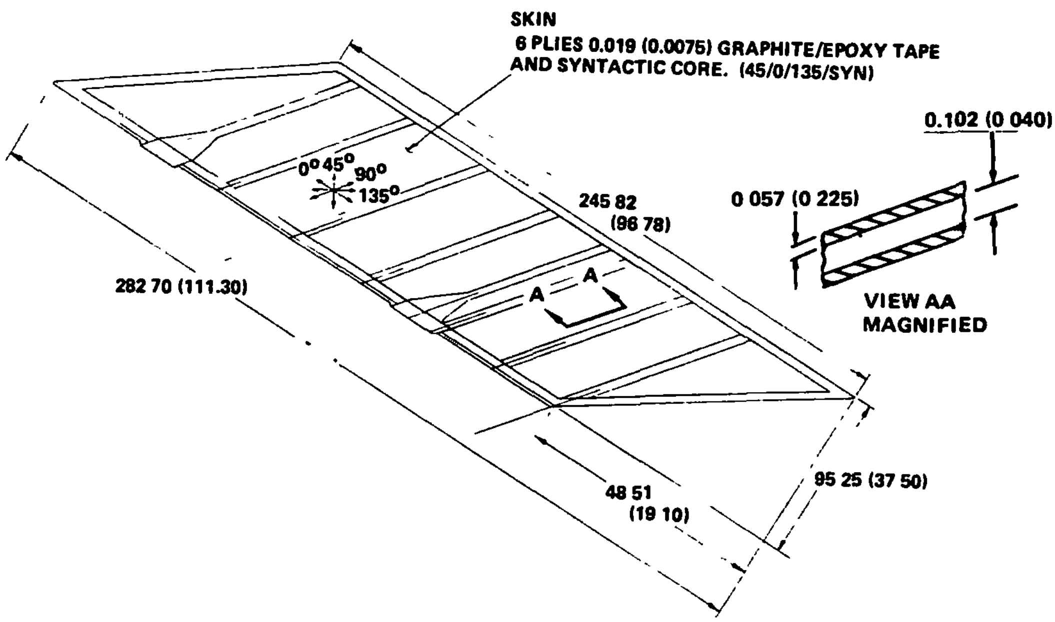


Figure 8. - Cover-concept #3 (All dimensions shown in cm (in.)).

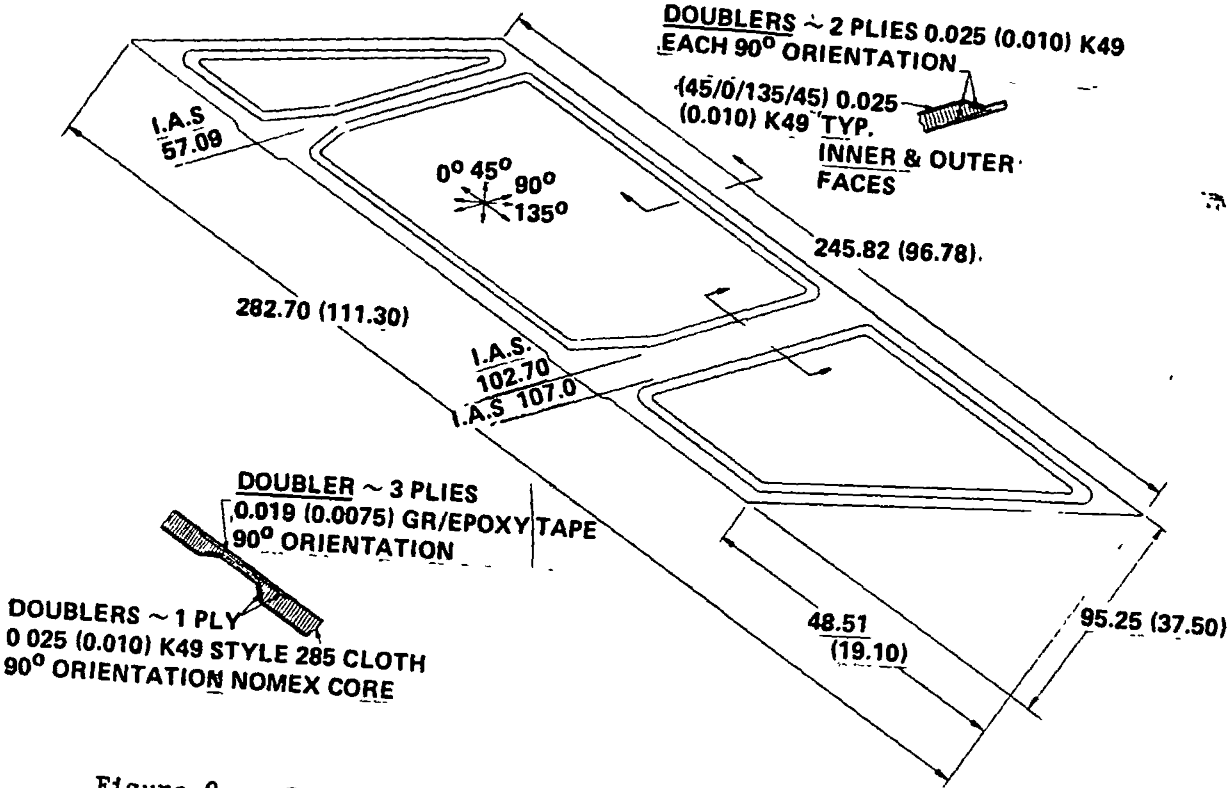


Figure 9. - Cover-concept #5 (All dimensions shown in cm (in.)).

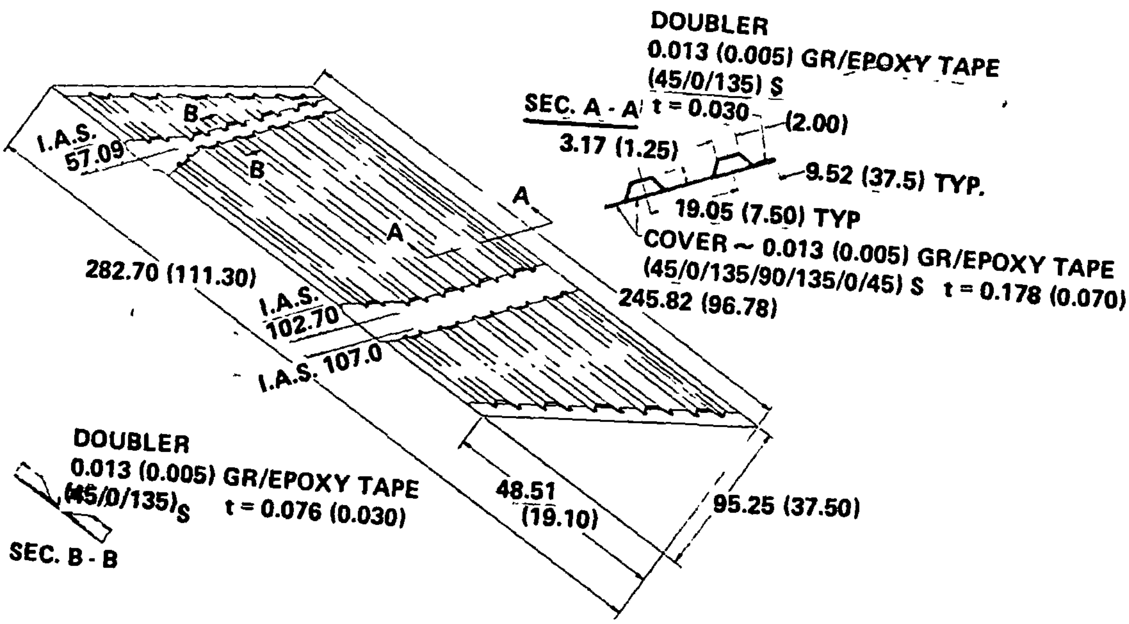


Figure 10. - Cover-concept #8 (All dimensions shown in cm (in.)).

TABLE 2. - COVER EVALUATION MATRIX

Concept	Sheet Skin						Honeycomb Sandwich			Stiffened Skin	
Concept No.	-	1	2	3	4	10	5	6	7	8	9
Material and Construction	AL	GR - 16 plies of 0.013 cm (5 mil) per ply tape	GR - 12 plies of 0.019 cm (7.5 mil) per ply tape	GR/SYN - 6 plies of 0.019 cm (7.5 mil) per ply tape and 1 ply of syntactic core 0.10 cm (0.040 in.)	GR/SYN - 12 plies of 0.013 cm (5 mil) per ply tape and 1 ply of syntactic core 0.08 cm (0.030 in.)	GR/SYN - 4 plies of 0.033 cm (13 mil) per ply fabric and 1 ply of syntactic core 0.09 cm (0.036 in.)	K49/Nomex - 4 plies of 0.025 cm (10 mil) per ply fabric with Nomex core	GR/Nomex - 4 plies of 0.019 cm (7.5 mil) per ply tape with Nomex core	Hybrid/Nomex - 4 plies of 0.019 cm (7.5 mil) per ply graphite tape and 4 plies of 0.025 cm (10 mil) per ply Kevler 49 with Nomex core	GR - 14 plies of 0.013 cm (5 mil) per ply tape skin with 5 hats	GR - 14 plies of 0.013 cm (5 mil) per ply tape skin with 6 hats
No. of Intermediate Ribs	13	6	10	5	4	5	0	0	0	0	1
Weight (1) kg (lb)	13.4 (29.6)	9.2 (20.3)	8.9 (19.6)	7.3 (16.0)	7.9 (17.5)	8.0 (17.2)	11.0 (24.2)	10.4 (23.0)	10.7 (23.6)	11.7 (25.8)	11.2 (24.6)
Cost Ratio (1)	1.00	0.92	1.20	0.88	0.91	0.93	0.67	0.82	0.72	0.99	1.15
Tooling and Manufacturing Processes	Current Design	G	F	F	G	G	G	F	F	F	P
Inspectability		G	G	G	G	G	F	F	F	F	F
Impact Resistance		G	F	G	G	G	F	P	P	F	F
Environmental Sensitivity		G	G	G	G	G	P	F	P	G	G
Maintainability		G	G	G	G	G	P	P	P	F	F
Repairability		G	G	G	G	G	F	F	F	P	P
Remarks (1) For 1 cover and half-depth ribs	Current Design	Requires Large No. of Rib Doublers	No-Bleed Process Preferable					Cocure Process is Preferable			

G-Good, F-Fair, P-Poor

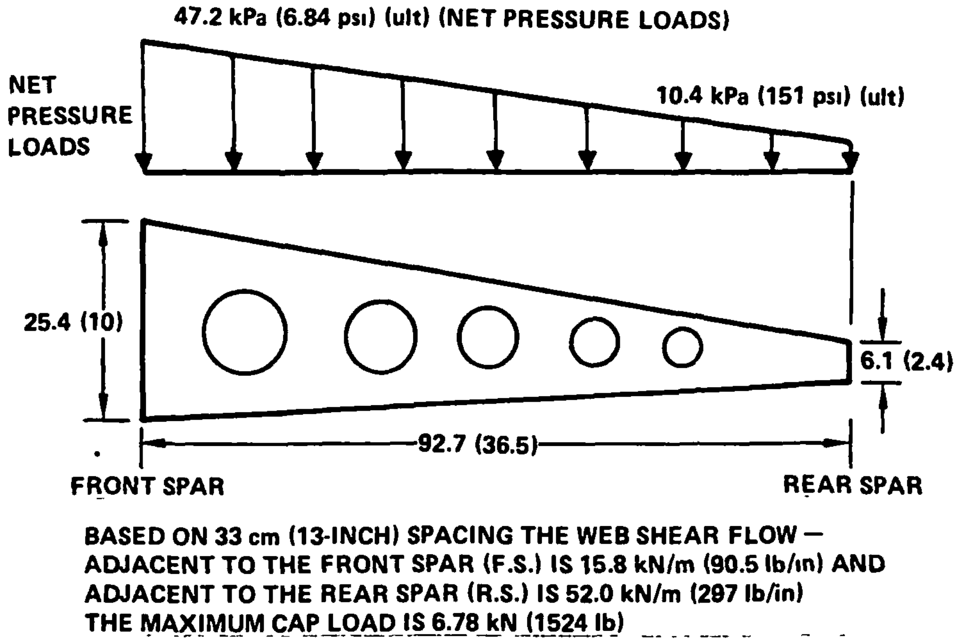


Figure 11. - Intermediate rib loads and geometry
(All dimensions shown in cm (in.)).

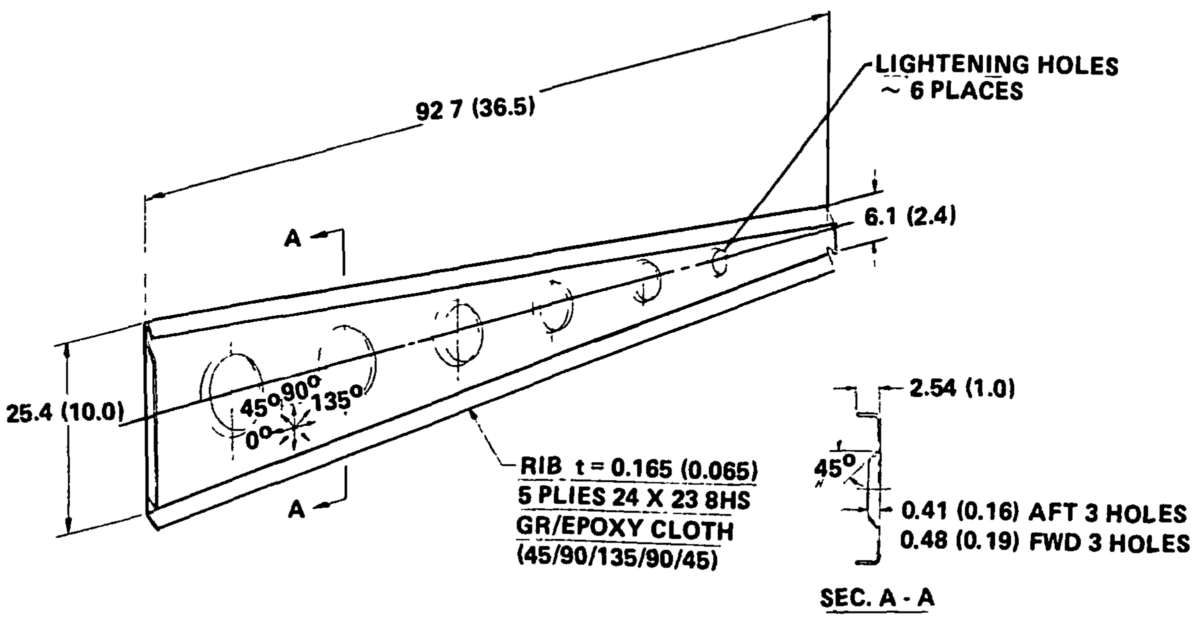


Figure 12. - Intermediate rib-concept #2
(All dimensions shown in cm (in.)).

TABLE 3. - INTERMEDIATE RIB EVALUATION MATRIX

Concept	Truss	Plain Web with Lightening Holes					
Concept No	-	1	2	3	4	5	6
Material and Construction	Aluminum	Graphite tape, 0 013 cm (5 mils) per ply, 12 plies in web and 16 plies in caps	Graphite fabric, 0.033 cm (13 mils) per ply 5 plies in web and caps	Graphite tape, 0 019 cm (7 5 mils) per ply, 6 plies in web with 1 ply of syntactic core, and 9 plies in caps	Graphite tape, 0 019 cm (7 5 mils) per ply, 6 plies in web with 2 plies of Kevler 49 fabric, and 9 plies in caps	Kevler 49 fabric, 0.025 cm (10 mils) per ply, 9 plies in web and caps.	Graphite tape, 0 019 cm (7 5 mils) per ply, 7 plies in web and 10 plies in caps
Weight (1) kg (lb) Cost Ratio	0 77 (1 71) 1 00	0 53 (1 17) 0.97	0.54 (1.20) 0.95	0.49 (1.09) 0 89	0.53 (1.17) 0.94	0.64 (1.41) 1.27	0.50 (1.11) 1.17
Tooling and Manufacturing Processes	Current Design	Fair	Good	Fair	Fair	Good	Fair
Inspectability		Good	Good	Good	Good	Good	Good
Impact Resistance		Good	Good	Good	Good	Good	Good
Environmental Sensitivity		Good	Good	Good	Good	Fair	Good
Maintainability		Good	Good	Good	Good	Good	Good
Repairability		Good	Good	Fair	Fair	Fair	Good
Remarks (1) Includes fasteners	Current Design	Separate cap and web layups add to complexity		Separate cap and web layups add to complexity	Separate cap and web layups add to complexity	Machineability of KEVLAR-49 accounts for slight disadvantage compared to all graphite	Separate cap and web layups add to complexity

for I.A.S. 57.1 and I.A.S. 102.7 is shown in figure 13. The rib at I.A.S. 107.1 is more lightly loaded since it only reacts actuator loads. A typical rib design for the I.A.S. 107.1 rib is shown in figure 14.

Five main rib concepts were designed and evaluated. The evaluation matrix for the main ribs at I.A.S. 57.1 and I.A.S. 102.7 is shown in table 4. Concepts #1 and #2 were selected for further analysis.

Rear spar. - The rear spar functions as a closeout member for the structural box portion of the aileron. All of the ribs, covers, and the trailing-edge wedge are mechanically fastened to the rear spar. Ultimate design loads for the rear spar are as follows: upper cap, 3203N (720 lb) tension, -3114N (-700 lb) compression; lower cap, 4893 N (1100 lb) tension, -511N (-1150 lb) compression; and shear web, 46410 N/m (265 lb/in.).

Two rear spar design concepts were evaluated, a new aluminum design and a graphite fabric design. Both designs have a channel cross section. A typical design is shown on figure 15. The aluminum rear spar used for the current metal aileron, an I section, cannot be used for the composite aileron because its geometry is not compatible with the composite covers.

The evaluation of the rear spar designs are shown in table 5. Based on these data, the new aluminum design was selected for use in the composite aileron.

Front spar. - The front spar ultimate design loads are a web shear flow of 4359 N (980 lb/in.) and cap loads of 47 685 N (10 720 pounds) tension and 42 258N (9500 pounds) compression. The spar web is stiffened by the ribs, hinge/actuator fittings, shroud supports, and feedback fittings.

Five composite concepts were sized in detail. The webs were analyzed using a stability analysis computer program with the effect of finite aspect ratio and holes included in the analysis. The spar cap stability was checked both in conjunction with the skin and with the skin assumed cut for fail-safe analysis.

Figure 16 illustrates the typical design of the front spar. Note that the web has six flanged access holes as required by the maintainability guidelines. To accommodate the varying loading intensities the cap flange widths vary from 3.38 cm (1.33 in.) to 6.35 cm (2.50 in.) depending on location.

Following preliminary design to satisfy structural requirements, each concept was evaluated for cost, weight, and the qualitative factors described previously. The results of this evaluation are summarized in table 6.

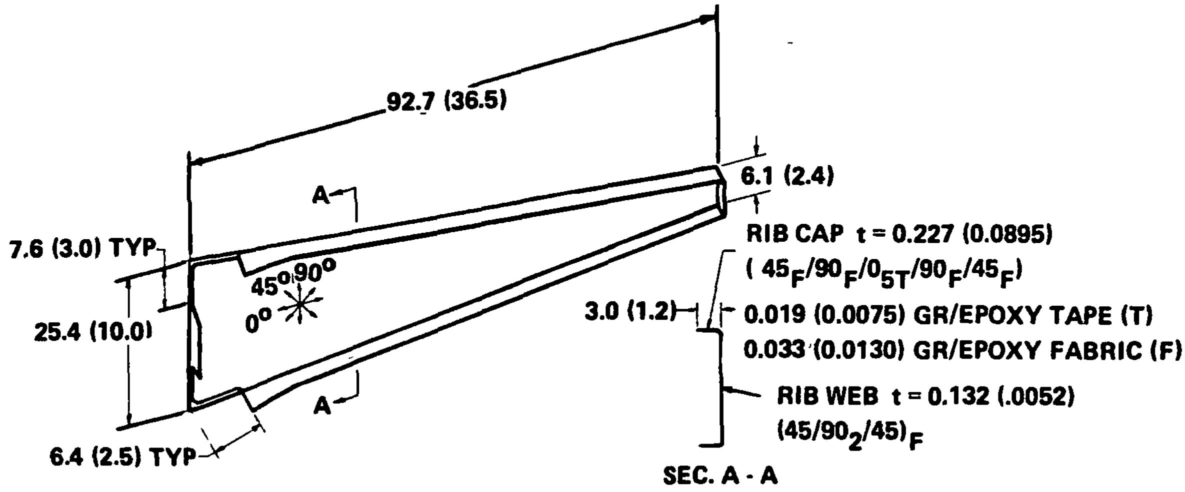


Figure 13. - Main ribs at I.A.S. 57.1 and I.A.S. 102.7 - concept #2 (All dimensions shown in cm (in.)).

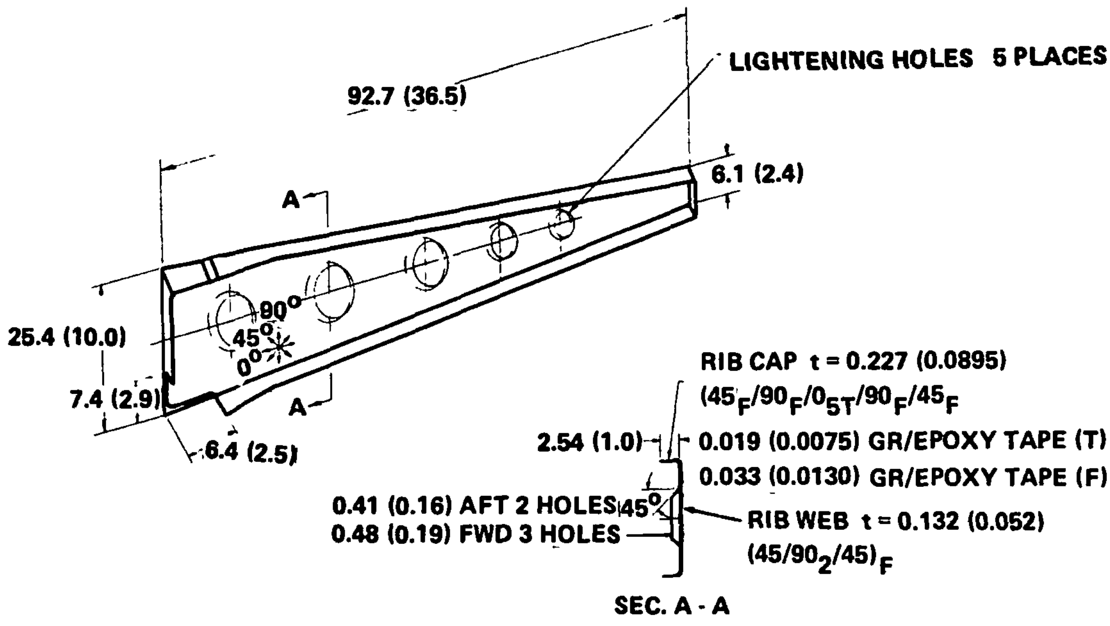


Figure 14. - Main rib at I.A.S. 107.1 - concept #2 (All dimensions shown in cm (in.)).

TABLE 4. - MAIN RIB EVALUATION MATRIX

Concept	Plain Web					Stiffened
Concept No.		1	2	3	4	5
Material and Construction	Aluminum	Graphite Tape, 0.019 cm (7.5 mils) per ply, 7 plies in web and 12 plies in caps	Graphite fabric webs, 4 plies at 0.033 cm (13 mils) per ply, and fabric and tape caps, 4 plies of fabric and 5 plies of 0.019 cm (7.5 mils) per ply tape	Graphite tape, 0.013 cm (5 mils) per ply, 6 plies in web with syntactic core, and 18 plies in caps	Graphite tape, 0.013 cm (5 mils) per ply, 8 plies in web with 2 plies of Kevler 49 fabric, and 14 plies in caps	Graphite tape, 0.019 cm (7.5 mils) per ply, 6 plies in web with bead stiffeness, and 11 plies in caps
Weight (1) kg (lb) Cost Ratio	2.47 (5.44) 1.00	1.59 (3.50) .92	1.58 (3.49) .98	1.52 (3.35) 1.01	1.61 (3.56) 1.02	1.58 (3.48) 1.05
Tooling and Manufacturing Processes		Good	Good	Fair	Fair	Poor
Inspectability		Good	Good	Good	Good	Poor
Impact Resistance	Current Design	Good	Good	Good	Good	Good
Environmental Sensitivity		Good	Good	Good	Fair	Good
Maintainability		Fair	Fair	Fair	Fair	Good
Repairability		Good	Good	Fair	Poor	Poor
Remarks (1) Includes fasteners & aluminum backup fittings	Current Design		Higher scrap 45° plies, 6 layup operations	Need for control in radius area: 0° cap and syntactic juncture	Greatest number of layup operations for plain webs. Machinery probs. with Kevlar	Difficult tooling

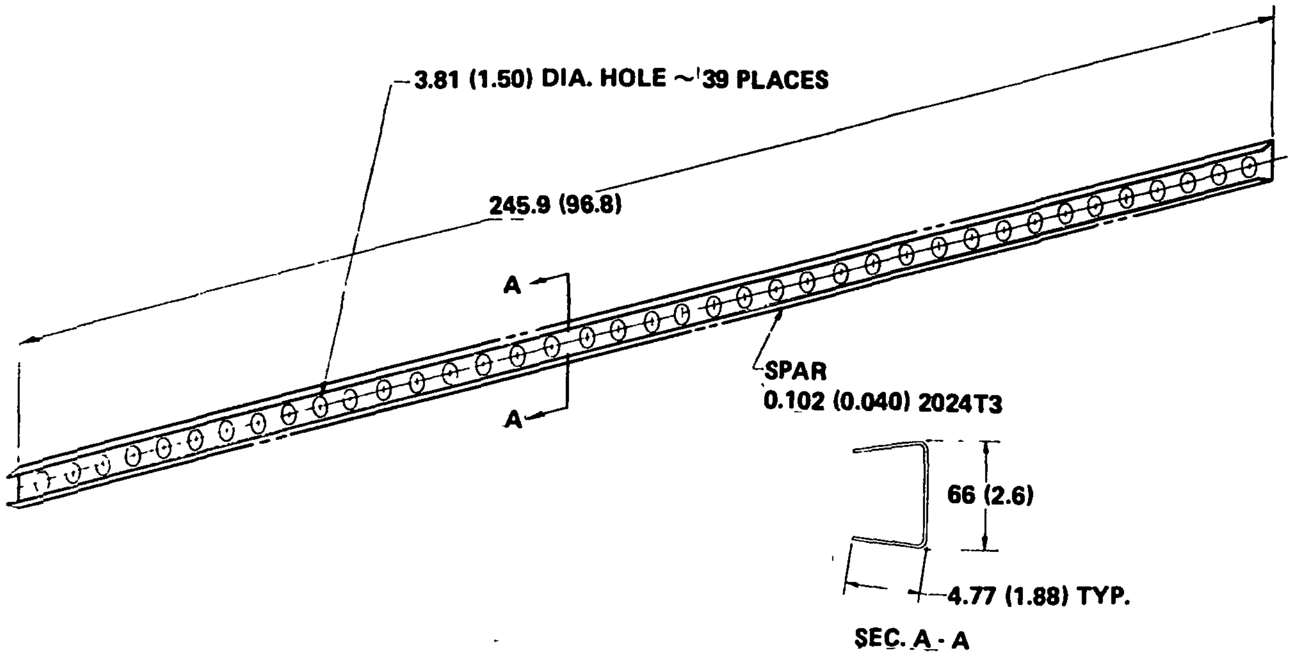


Figure 15. - Aileron rear spar new aluminum design (All dimensions shown in cm (in.)).

TABLE 5. - REAR SPAR EVALUATION MATRIX

Concept	I-Beam	Channel	
Material and Construction	Aluminum Extrusion	Aluminum Channel 0.102 cm (0.040 in.) 2024-T3	Graphite fabric, 4 plies, 24x23 8HS (0.033 cm (13 mils)/ply))
Weight ① kg (lb)	1.36 (3.0)	1.32 (2.9)	1.04 (2.3)
Cost Ratio	1.00	0.97	5.22
Tooling and Manufacturing Processes	Current design	Good	Fair
Inspectability		Good	Good
Impact Resistance		Good	Good
Environmental Sensitivity		Good	Good
Maintainability		Good	Good
Repairability		Good	Fair
Remarks ① Includes fasteners	Current design	Requires penetrant inspection only	

TABLE 6. - FRONT SPAR EVALUTION MATRIX

Concept	I Section	Channel Section				
Concept No.	-	1	2	3	4	5
Material and Construction	Aluminum	Graphite tape and fabric 4 plies each 0.019 cm (7.5 mil) tape and 24 x 23 8 hs 0.033 cm (13 mils)/ply web and caps	Graphite tape, fabric and synthetic core, 4 plies tape 0.019 cm (7.5 mil) 2 plies 0.033 cm (13 mil) cloth, 0.76 cm (0.30 in) syntactic core web. Repl. core with 4 plies tape for cap	Graphite tape, Kevlar 49 fabric. 8 plies 0.013 cm (5 mil) tape with 4 plies 0.025 cm (10 mil) Kevlar cloth web, replace Kev. with 8 plies of tape for cap	All preplied Graphite Tape 10 plies of 0.019 cm (7.5 mil) tape common to web and cap	All graphite fabric 0.033 cm (13 mil) ply 6 plies in web 7 plies in cap
Weight 1 kg (lb) Cost Ratio	5.26 (11.59) 1.00	2.17 (4.78) 1.09	1.90 (4.19) 1.16	2.01 (4.43) 1.16	1.98 (4.37) 0.83	2.15 (4.75) 1.09
Tooling and Manufacturing Processes	Current Design	Good	Fair	Fair	Good	Good
Inspectability		Fair	Fair	Good	Fair	Fair
Impact Resistance		Good	Good	Good	Good	Good
Environmental Sensitivity		Good	Good	Fair	Good	Good
Maintainability		Good	Fair	Good	Good	Good
Repairability		Good	Fair	Poor	Good	Good
Remarks 1 Includes fasteners	Current Design		Complex syntactic junction	Greatest number of layup operations. Machinability problems with Kevlar		Requires splices in 45° plies

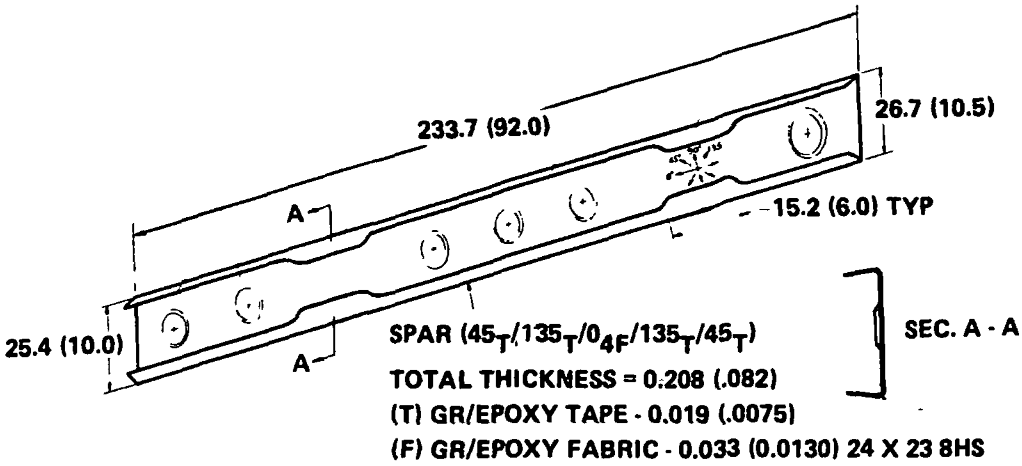


Figure 16. - Front spar-concept #1 (All dimensions shown in cm (in.)).

Rib backup fittings. - Rib backup fittings are used to redistribute concentrated loads from actuators and hinges into the rib web and cap, and the cover. The maximum load is applied to the hinge fitting at IAS 102.7 and is reacted through the upper pair of fittings. The maximum load is 58 383 N (13 125 pounds); a 15 percent fitting factor is maintained. Data from previous tests of similar fittings (see reference 2) were used to size an all-graphite tape, 16 plies at 0.019 cm (7.5 mils)/ply), an all-graphite cloth, 10 plies at 0.033 cm (13 mils)/ply), and a 7075-T6 aluminum die forging fitting. Concept #1 is shown in figure 17.

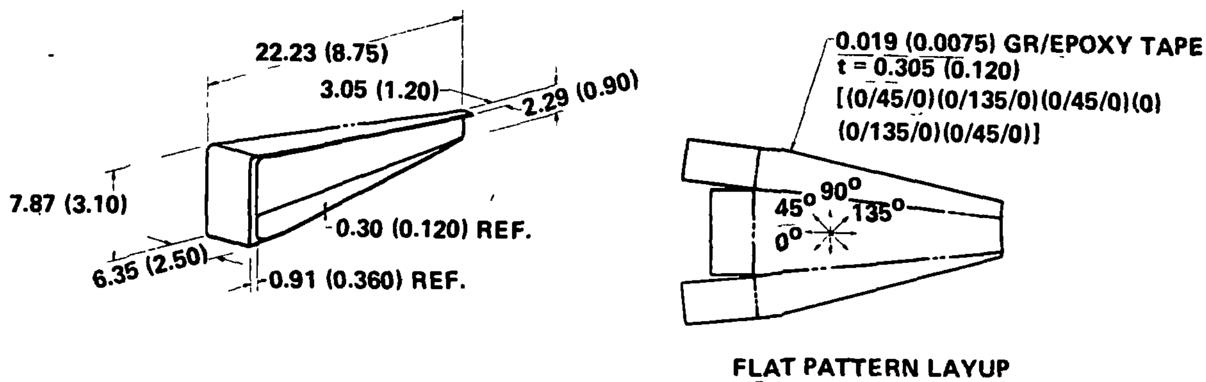


Figure 17. - Hinge and actuator rib backup fitting-concept #1, (All dimensions shown in cm (in.)).

The evaluation matrix for the three rib backup fitting designs is shown in table 7. Based on this evaluation, concept #3, the aluminum design, was selected for use in the composite aileron.

Assembly evaluation. - The evaluation of the cover concepts led to the selection of two configurations for further evaluation as ACA assemblies. These configurations were the graphite/syntactic core with five intermediate ribs and the Kevlar 49 fabric/honeycomb sandwich with no intermediate ribs. The two cover concepts were then combined with the preliminary selections for each of the subcomponents evaluated. The two assembly designs are shown in figures 18 and 19, and the evaluation of these designs is given in table 8.

Analysis of the data presented in table 8 indicates that the multirib design, concept #2, offers the greatest potential for meeting objectives. The weight savings for the multirib design is greater than 25 percent, whereas the sandwich design failed to reach the targeted 20 percent weight savings. Furthermore, the qualitative factors favored the multirib design. Both concepts are predicted to be cost competitive with the current metal aileron. Thus the multirib configuration was selected.

TABLE 7. - RIB BACKUP FITTING EVALUATION MATRIX

Concept	Bathtub		
Material	GR - Tape #1	GR - Cloth #2	Aluminum #3
Weight kg (lb)	0.22 (0.48)	0.24 (0.52)	0.32 (0.70)
Cost Ratio	1.00	1.07	0.18
Tooling and Manufacturing Processes	Poor	Poor	Good
Inspectability	Fair	Fair	Good
Impact Resistance	Good	Good	Good
Environmental Sensitivity	Good	Good	Fair
Maintainability	Fair	Fair	Fair
Repairability	Not applicable 1	Not applicable 1	Not applicable 1
Remarks	1 Replace Fitting	1 Replace Fitting	1 Replace Fitting

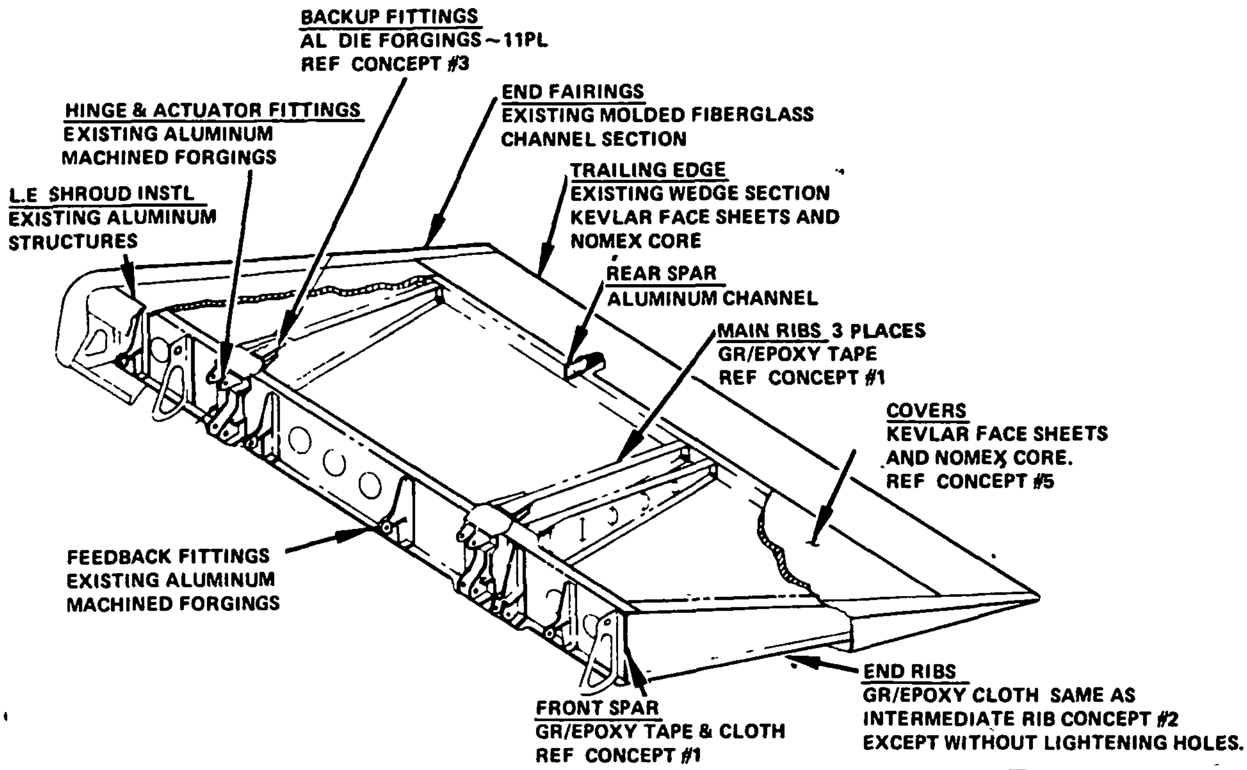


Figure 18. - Aileron-concept #1.

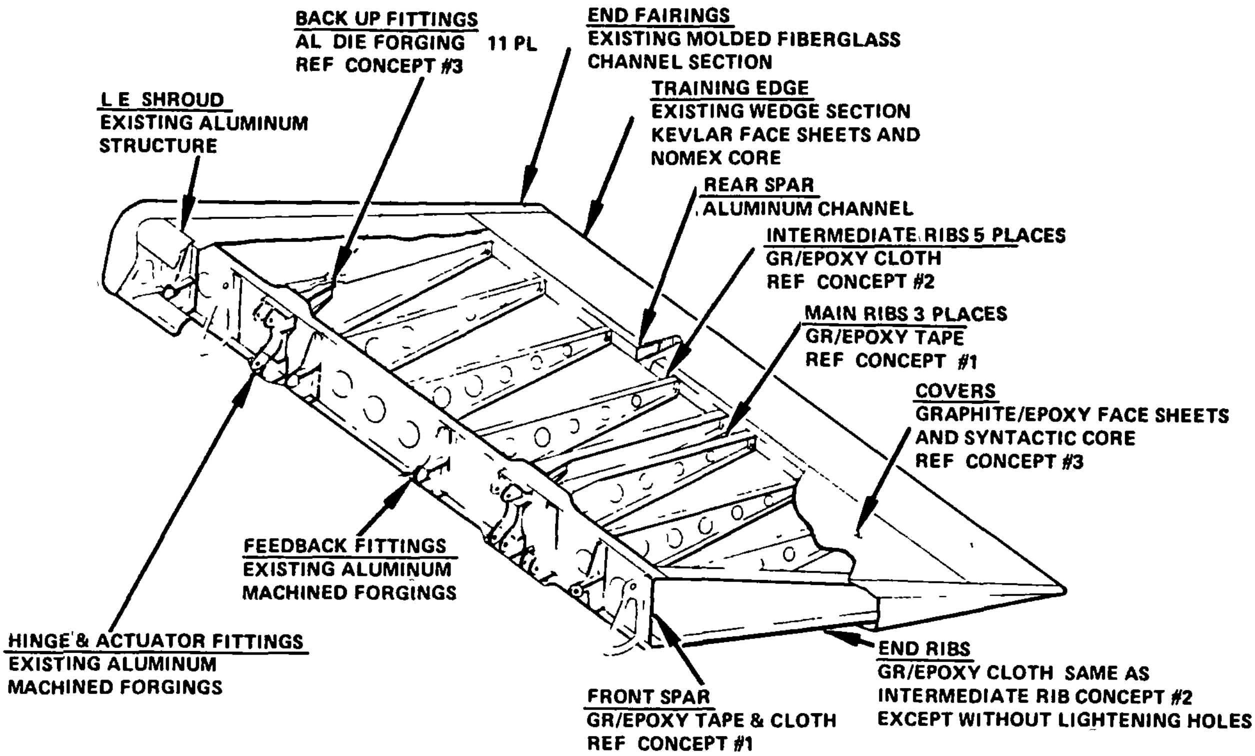


Figure 19. - Aileron-concept #2.

TABLE 8. - AILERON ASSEMBLY EVALUATION MATRIX

Component	Inboard Aileron Assembly		
Concept and Materials	Multirib-Aluminum	Sandwich - Composite #1	Multirib - Composite #2
Cover	Sheet - AL	#5 Kevlar Face/Nomex Core	#3 Gr. Tape/Syntact. Core
Front Spar	I Section - AL	#1 Gr. Tape/Fabric	#1 Gr. Tape/Fabric
Rear Spar	I Section - AL	Aluminum Channel	Aluminum Channel
Main Ribs	Plain Web - AL	#1 Gr. Tape	#1 Gr. Tape
Intermediate Ribs	Truss - AL	Not required	#2 Gr. Fabric
End Ribs	Stiffened - AL	Gr. Fabric	Gr. Fabric
Back-Up Fittings	Bathtub - AL	#3 AL. Die Forgings	#3 AL. Die Forgings
No. of Subassemblies	27	6	14
No. of Fasteners	3112	1394	1634
Weight kg (lb)	63.7 (140.4)	54.2 (119.5) (1)	47.7 (105.1) (1)
Cost Ratio	1.00	0.90	0.94
Tooling and Manufacturing Processes	Current Design	Good	Fair
Inspectability		Fair	Good
Impact Resistance		Fair	Good
Environmental Sensitivity		Poor	Good
Maintainability		Good	Fair
Repairability		Good	Good

REMARKS: (1) Includes 5% growth.

Material trade studies indicated advantages for both fabric and preplied tape. Consequently, design iterations were required to determine the interaction between design concepts and material form and to determine the best combination of both. Subcomponent designs described previously were used to develop aileron assemblies using: all-graphite preplied tape, assembly concept #3; all-graphite fabric, assembly concept #4; and the best combination of tape and fabric, assembly concept #5. The results of this study are summarized in table 9.

Selected ACA design concept. - A review of the assemblies depicted in table 9 showed that concept #5 with fabric ribs and graphite tape front spar and graphite tape covers with syntactic core represented the most effective design. The selected concept is shown in figure 20, and its weight statement is shown in table 10.

TABLE 9. - CONCEPT/MATERIALS REFINEMENT

Component Description	Assembly Concept Number			
	#2	#3	#4	#5
Cover (Table 2)	Tape #3	Tape #3	Fabric #10	Tape #3
Front Spar (Table 6)	Tape & Fabric	Tape #4	Fabric #5	Tape #4
Intermediate and End Ribs (Table 3)	Fabric #2	Tape #6	Fabric #2	Fabric #2
Main Ribs (Table 4)	Tape #1	Tape #1	Fabric #2	Fabric #2
Rear Spar (Table 5)	Al	Al	Al	Al
Backup Fitting (Table 7)	Al	Al	Al	Al
Weight* kg (lb)	45.4 (100.0)	44.9 (98.9)	46.4 (102.4)	45.2 (99.6)
Cost Ratio to Aluminum	0.94	--	--	0.93

*Without Design Growth Allowance

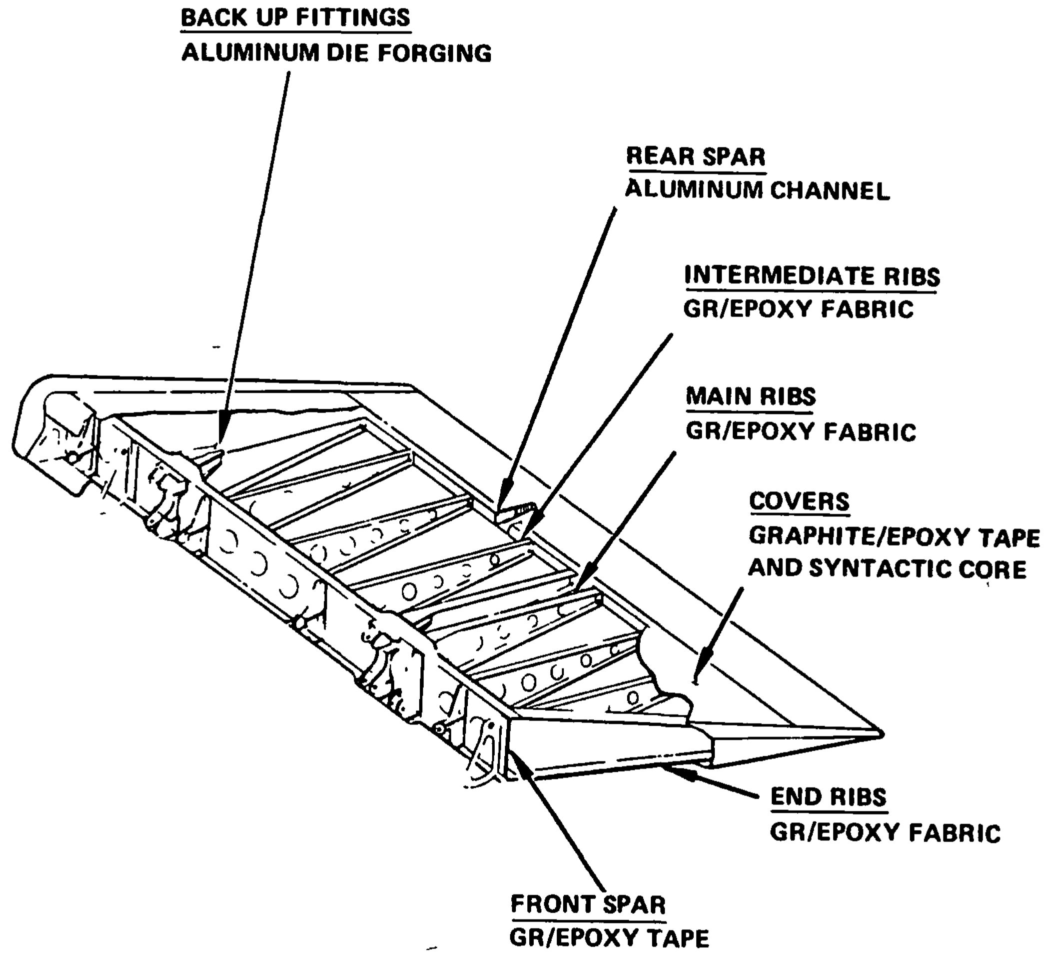


Figure 20. - Selected ACA concept and materials.

TABLE 10. COMPOSITE AILERON WEIGHT BREAKDOWN

Component	Aluminum Baseline Weight kg (lb)	Composite Concept #5 Weight kg (lb)
Surfaces ①	17.8 (39.3)	13.0 (28.7)
Ribs ②	17.8 (39.3)	[9.1 (20.0)]
IAS 57		1.8 (3.9)
102		1.8 (3.9)
107		1.4 (3.0)
INBD Closeout		0.7 (1.6)
OUTBD Closeout		0.7 (1.6)
Intermediate ⑤		2.7 (6.0)
Spars ②	7.2 (15.9)	[4.4 (9.7)]
Front		2.6 (5.8)
Rear		1.8 (3.9)
Fairing & Shrouds ② ③	7.4 (16.2)	[7.7 (16.9)]
LE Shroud		4.8 (10.5)
INBD Fairing		1.3 (2.9)
OUTBD Fairing		1.6 (3.5)
T.E. Wedge Assy ④	5.7 (12.6)	2.7 (6.0)
Attach Hardware ⑤	1.9 (4.2)	1.2 (2.7)
Surface Protection	1.6 (3.4)	[2.7 (6.1)]
Lightning ⑥		1.2 (2.7)
Finish/Sealant		1.5 (3.4)
Existing Front Spar FTGS ①	4.3 (9.5)	4.3 (9.5)
Design Growth Allowance	-	2.3 (5.0)
Predicted Weight - Aileron	63.7(140.4)	47.4(104.6)
Weight Saving		16.3 (35.8)
% Weight Saving		25.5%

NOTES:
① No fasteners
② Including: upper surface fasteners; lower surface platenuts
③ Identical to baseline except Hi-Loks instead of rivets for shroud to spar attachment
④ Including: fasteners (bolts & washers)
⑤ Remaining assembly and installation hardware
⑥ Aluminum flame spray

MATERIAL EVALUATION

Material evaluation activities in Task I consisted of initial qualitative screening and analysis of candidate prepregs and adhesives, followed by a quantitative screening test program of selected candidate prepregs. The quantitative screening included structural tests conducted at Lockheed and producibility tests conducted at Avco.

Qualitative Analysis

The qualitative analysis was conducted to select composite materials and adhesives to be quantitatively evaluated. The requirements on which this evaluation was based are shown in table 11. The inboard aileron is subjected to temperatures greater than 355.9°K (181°F) due to solar heating, thus only resins and adhesives which cure at 422.0°K (300°F) to 449.8°K (350°F) were considered. Since several concepts and materials were being investigated for the ACA, it was necessary to evaluate unidirectional graphite tape, graphite cloth, and Kevlar 49 cloth reinforcements. Design concepts for the covers include several honeycomb sandwich configurations. Consequently, adhesives were also evaluated.

TABLE 11.-MATERIAL REQUIREMENTS

<u>Environmental</u>

- 219.3°K/(-65°F) to 355.9°K (181°F); with approximately 67% of saturation moisture weight gain in service; impact resistant; hail, FOD, rain; lightning; U.V. protection; hydraulic fluid.

<u>Design</u>

- Adaptability to various design concepts such as honeycomb or syntactic sandwich and hybrid constructions.

<u>Structural</u>

- High specific stiffness, good strength property retention under adverse environment.

<u>Producibility</u>

- Fiber/resin control (low resin content)
- Shelf life, tack, drape, handleability
- Flow, gelatin, low bleed
- Preply
- Machinability

An initial qualitative screening procedure was conducted on potential reinforcements and resins to narrow the field to those which would be the subject of a detailed qualitative analysis. The principal discriminator used for this initial screening was data availability. Table 12 shows the results of the initial screening. Four resins were selected for further evaluation: Narmco 5208, Fiberite 934, Hexcel F263, and Hercules 3501, combined with the selected reinforcement types: T300 unidirectional graphite tape; AS unidirectional graphite tape for the 3501 resin; T300 bidirectional graphite fabric; and Style 285 Kevlar 49 fabric.

The qualitative analysis of the four candidate systems is shown in table 13. Three matrix systems, 5208, 934 and F263, were selected for quantitative screening with the three selected reinforcement types. The fourth system, 3501/AS, was eliminated for the following reasons:

- Test data indicates that this system has a lower modulus than the other systems being considered. Since the aileron is a stiffness-critical structure, selection of this system would result in a lower weight savings.

- The vendor has little experience with either graphite cloth or Kevlar 49 cloth.

Quantitative Analysis

The quantitative analysis which was conducted on three composite systems consisted of structural screening tests, including environmental and impact tests performed at Lockheed, and producibility screening tests performed at Avco.

Structural screening tests. - The quantitative structural screening tests are outlined in table 14. Fabrication of test specimens required a preliminary process development to ensure that the specimens are representative of production components. This task was closely coordinated with the fabricability studies at Avco.

The quantitative screening and the fabricability studies investigated three resin matrices: Narmco 5208, Fiberite 934, and Hexcel F-263, on each of the three filamentary reinforcement forms. These include unidirectional graphite tape, bidirectional graphite fabric, and Style 285 Kevlar 49 fabric. These resin-fiber combinations were evaluated as honeycomb sandwich skins, syntactic epoxy sandwich skins, and graphite/Kevlar 49 hybrids, as well as monolithic laminates. Low-resin content prepregs (35 percent resin content by weight, nominal) were used in the evaluation.

Laminate tests. - Twelve laminates were fabricated using the vendor's recommended cure cycle for the laminate tests. Following fabrication each laminate was ultrasonically inspected and portions of the laminate subjected to

TABLE 12. - INITIAL QUALITATIVE SCREENING

Material	Data Availability	Remarks
Reinforcements		
Graphite-Undirectional		
Union Carbide T300-3000	Yes	Wide usage - aerospace
T300-6000	No	Wide usage - commercial
Hercules AS-10000	Yes	Wide usage - aerospace
AS-3000	No	relatively new, little data available
Celanese C-3000	No	Relatively new fibers, vendor data indicates properties equal to UC T300-3000
C-6000	No	
Graphite - Bidirectional Fabric		
T300-3000	Yes	Most widely characterized graphite cloth
T300-1000	No	Higher cost than T300-3000
AS-3000	No	Relatively new, little data available
Kevlar 49 - Fabric		
DuPont Style 181	Yes	Greater cost than 281 or 285
Style 281	Yes	
Style 285	Yes	Better drapability than 281
Resins		
Narmco 5208	Yes	Currently in use at Lockheed
5235	No	Commercial version
Hercules 3501	Yes	Little data available on K49/3501
3502	No	Moisture/temperature resistant version
Fiberite 934	Yes	Currently in use at Lockheed
976	No	Moisture/temperature resistant version
Hexcel F263	Yes	Currently in use at Lockheed
U.S. Poly E788	No	
E793	No	
Ferro 9015	No	
3M SP-286	Some	Higher cost than other systems

TABLE 13. - QUALITATIVE MATERIAL SCREENING

Material	Usage and Production Experience	Strength/ Stiffness/Durability	Costs	Availability on Gr. and K-49 Fabric	Preplying Capability	Low Resin Content Tape Availability	Processibility
Narmco T300/5208	Extensive Calac/ Industry	Outstanding hot, wet properties. Good balance of mechanicals	Moderate	Yes	Capability by early '79	35±3%	High flow characteristics process is being developed on ACVF
Fiberite T300/934	Extensive LMSC/ Industry	Good hot, wet properties. Good balance of mechanicals	Moderate	Yes	No plans for this capability	35±3%	Lower flow than 5208. Satisfactory prebleeding. Process developed by CALAC
Hexcel T300/F263	Some Experience Calac/ LMSC	Good hot, wet properties. Good balance of mechanicals	Moderate	Yes	Plan to have capability, contingent on market justification	34.5±2.5	Comparable to 934
Hercules AS/3501	Extensive Gelac/ Industry	High strength, with reduced modulus compared to others. Hot properties adequate	Lowest	Yes, but Hercules has little fabric experience	Current capability	35±3%	Comparable to 934

TABLE 14. - QUANTITATIVE SCREENING TEST PLAN

Type Of Test	(a) Temperature	Graphite Tape (g)			Graphite Cloth (h)			Graphite Tape/ Syntactic			Kevlar Cloth (i)			Hybrid		
		(e) A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Sandwich Beam Compression	RTD	(f) 3	3	3	-	-	-	-	-	-	(f) 3	3	3	(f) 3	3	3
Interlaminar Tension	RTD	(f) 3	3	3	-	-	-	(b) 3	3	3	(f) 3	3	3	(f) 3	3	3
Sandwich Beam (c) Compression After Impact	RTD	(f) 3	3	3	-	-	-	(b) (d) 3	3	3	(f) 3	3	3	(f) 3	3	3
Laminate Compression	$355.4^{\circ}K$ ($180^{\circ}F$) Wet	3	3	3	-	-	-	(b) 3	3	3	-	-	-	-	-	-
Laminate Short-Beam Shear	RTD $219.3^{\circ}K$ ($-65^{\circ}F$) Dry $355.4^{\circ}K$ ($180^{\circ}F$) Wet	3 - 3	3 - 3	3 - 3	3 - 3	3 - 3	3 - 3	(b) 3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3
Laminate Flexure	RTD $255.4^{\circ}K$ ($180^{\circ}F$) Wet	3 3	3 3	3 3	3 3	3 3	3 3	(b) 3 3	3 3	3 3	3 3	3 3	3 3	3 3	3 3	3 3
Dynamic Mechanical Analysis	Dry Wet	3 3	3 3	3 3	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -

NOTES:

(a) Numbers in temperature column indicate test temperature in degrees Fahrenheit. Letters W - wet (7 day immersion at $338.7^{\circ}K$ ($150^{\circ}F$), D - dry, and RT - room temperature.

(b) A syntactic material (Hysol ADX 819) is used for the core.

(c) After impact the sandwich is tested as a beam with the impacted face in compression.

(d) After impact the Graphite tape/syntactic sandwich is tested in edgewise compression with platen supports.

(e) The letters A, B, and C are the resins (5208, 934 & F263) selected from qualitative screening.

(f) Bonded with AF143 adhesive.

(g) Nominal 0.013 cm (5 mils)/cured ply tape, 3000 tow fibers at 35% nominal resin content by weight.

(h) 24 x 23 8 harness satin bidirectional fabric 0.033 cm (13 mils)/cured ply nominal, 3000 tow fibers, at 35% nominal resin content by weight.

(i) Style 285 Kevlar 49 fabric, 43% nominal resin content by weight, 0.025 cm (10 mils)/cured ply nominal.

photomicrographic examination as part of the acceptance procedures. Once the laminate had been approved for testing it was machined into coupons which in turn were visually inspected and their dimensions recorded.

The objectives of the laminate tests were to compare the performance of the three candidate resins and to determine the compatibility of each resin with the reinforcements being considered for the ACA. To accomplish this objective three types of tests were conducted on each laminate: 0° flexure, short beam shear, and interlaminar tension. These tests were conducted at various environmental conditions to ascertain the comparative environmental stability of the candidate resin systems. Full-fixity inplane compression tests were also conducted on specimens from the graphite tape laminates and graphite/syntactic laminates for further performance comparisons. For all tests a minimum of three replicates were tested. Test data from the laminate tests is given in tables 15 through 19.

Dynamic mechanical analysis. - For dynamic mechanical analysis (DMA), a test specimen was subjected to oscillations at a fixed maximum displacement, the frequency was varied at a fixed temperature and these tests repeated over a range of temperatures. Use of the measured forcing function allows curves to be plotted showing dynamic modulus as a function of temperature. These curves delineate phase transition temperatures and thus indicate the allowable working temperature of the materials being tested.

Coupons from the graphite tape laminates were tested in the three point bending mode using the equipment shown in figure 21. Both unconditioned and moisture conditioned specimens were tested at three frequencies, 0.01 Hz, 0.1 Hz, and 1.0 Hz. The average dynamic modulus for the three frequencies is shown as a function of temperature for the candidate materials in figure 22. It was concluded that the Thornel 300/5208 material had the highest working temperature for both dry and conditioned samples.

Impact tests. - Impact tests were conducted on honeycomb core sandwich panels and syntactic core sandwich panels to compare the impact resistance of the three candidate resins when used to fabricate typical covers.

Sketches of the impact test panels showing the impact locations and the locations of the coupons cut from the panels are shown in figures 23a, 23b, and 23c. Testing on the panels was accomplished by dropping a spherically rounded, 591 gram (1.30 lb) steel weight on the panels. This weight when dropped from a height of 56.51 cm (22.25 in.) onto the panel generates a kinetic energy of 2.71J (2.0 ft lb). The panels were simply supported around each edge by a specially built frame. Figure 24 shows the impact test setup. Each impact was photographed by motion pictures. The velocity of each drop was determined from these motion pictures.

TABLE 15. - SUMMARY OF GRAPHITE TAPE LAMINATE TEST RESULTS (LAMINATE ORIENTATION: $(0^o/45^o/0^o/135^o)_{2S}$)

0^o Flexure

Resin	Fiber Volume %	297^oK (75^oF) dry				355.4^oK (180^oF) wet*			
		Stress		Modulus		Stress		Modulus	
		MPa	(ksi)	GPa	(10^6 psi)	MPa	(ksi)	GPa	(10^6 psi)
5208	67.5	1216	(176.3)	101.0	(14.6)	162	(168.5)	144.8	(21.0)
934	66.5	1291	(187.2)	95.9	(13.9)	1118	(162.1)	137.0	(19.9)
F263	63.8	1099	(159.[illegible])	84.8	(12.3)	940	136.3	89.0	(12.9)

0^o Short Beam Shear

Resin	Fiber Volume %	297^oK (75^o) dry		219.3^oK (-65^oF) dry		355.4^oK (180^oF) wet*	
		Stress		Stress		Stress	
		MPa	(ksi)	MPa	(ksi)	MPa	(ksi)
5208	67.5	51.2	(7.42)	-	-	50.3	(7.30)
934	66.5	76.1	(11.03)	-	-	62.8	(9.10)
F263	63.8	49.2	(7.13)	-	-	34.4	(4.99)

0^o Compression and Interlaminar Tension

Resin	Fiber Volume %	0^o Compression				Interlaminar Tension	
		355.4^oK (180^oF) wet*				297.0^oK (75^oF) dry	
		Stress		Modulus		Stress	
		MPa	(ksi)	GPa	(10^6 psi)	MPa	(ksi)
5208	67.5	714.6	(103.8)	72.2	(10.47)	9.24	(1.34)
934	66.5	705.6	(102.3)	70.1	(10.17)	16.07	(2.33)
F263	63.8	517.3	(75.0)	6[illegible]	(9.70)	9.66	(1.40)

*Wet conditioned by 168 Hour Immersion in Water at 338.7^oK (150^oF)

TABLE 16. - SUMMARY OF GRAPHITE FABRIC LAMINATE TEST RESULTS
(LAMINATE ORIENTATION: $(0^{o}/45^{o}/135^{o})_{s}$)

0^{o} Flexure									
		297^{o}K (75^{o}F) dry				355.4^{o}K (180^{o}F) wet*			
	Fiber Volume	Stress		Modulus		Stress		Modulus	
Resin	%	MPa	(ksi)	GPa	(10^{6}psi)	MPa	(ksi)	GPa	(10^{6}psi)
5208	67.0	684.9	(99.3)	58.6	(8.5)	733.9	(106.4)	66.2	(9.6)
934	61.0	688.4	(99.8)	53.	(7.7)	550.4	(79.8)	53.8	(7.8)
F263	67.0	691.1	(100.2)	60.7	(8.8)	498.7	(72.3)	59.3	(8.6)

0^{o} Short Beam Shear							
		297.0^{o}K (75^{o}F) dry		219.3^{o}K (-65^{o}F) dry		355.4^{o}K (180^{o}F) wet*	
	Fiber Volume	Stress		Stress		Stress	
Resin	%	MPa	(ksi)	MPa	(ksi)	MPa	(ksi)
5208	67.0	61.5	(8.92)	-		56.4	(8.18)
934	61.0	71.5	(10.37)	-		58.0	(8.41)
F263	67.0	69.6	(10.09)	-		47.4	(6.87)

*Wet conditioned by 168 Hour Immersion in Water at 338.7^{o}K (150^{o}F).

TABLE 17. - SUMMARY OF KEVLAR 49 FABRIC LAMINATE TEST RESULTS (LAMINATE ORIENTATION: $(45^\circ/0^\circ/135^\circ/45^\circ)_s$)

0° Flexure

Resin	Fiber Volume %	297°K (75°F) dry				355.4°K (180°F) wet*			
		Stress		Modulus		Stress		Modulus	
		MPa	(ksi)	GPa	(10^6psi)	MPa	(ksi)	GPa	(10^6psi)
5208	60.2	291.7	(42.3)	20.0	(2.9)	212.4	(30.8)	15.2	(2.2)
934	56.6	220.7	(32.0)	12.4	(1.8)	213.8	(31.0)	9.7	(1.4)
F263	61.1	238.6	(34.6)	12.4	(1.8)	212.4	(30.8)	11.7	(1.7)

0° Short Beam Shear

Resin	Fiber Volume %	297°K (75°F) dry		219.3°K (-65°F) dry		355.4°K (180°F) wet*	
		Stress		Stress		Stress	
		MPa	(ksi)	MPa	(ksi)	MPa	(ksi)
5208	60.2	26.4	(3.83)	25.9	(3.75)	17.4	(2.53)
934	56.6	25.9	(3.76)	20.6	(2.98)	20.5	(2.97)
F263	61.1	21.5	(3.12)	22.1	(3.20)	16.7	(2.42)

Interlaminar Tension

Resin	Fiber Volume %	297°K (75°F) dry	
		Stress	
		MPa	(ksi)
5208	60.2	11.6	(1.69)
934	56.6	9.2	(1.34)
F263	61.1	9.9	(1.44)

*Wet conditioned by 168 Hour Immersion in Water at 338.7°K (150°F)

TABLE 18. - SUMMARY OF GR-K49 HYBRID LAMINATE TEST RESULTS
(LAMINATE ORIENTATION: $(0^{o}{}_{K}/\ 45^{o}{}_{2G}/0^{o}{}_{K})_{s}$)

0^{o} Flexure

Resin	Fiber Volume %	297°K (75°F) dry				355.4°K (180°F) wet*			
		Stress		Modulus		Stress		Modulus	
		MPa	(ksi)	GPa	(10^6 psi)	MPa	(ksi)	GPa	(10^6 psi)
5208	-	406	(58.9)	35.9	(5.2)	374	(54.3)	29.0	(4.2)
934	-	435	(63.1)	24.1	(3.5)	388	(56.3)	15.9	(2.3)
F263	-	375	(54.4)	23.5	(3.4)	379	(54.9)	22.1	(3.2)

0^{o} Short Beam Shear

Resin	Fiber Volume %	297°F (75°F) dry		219.3°K (-65°F) dry		355.4°K (180°F) wet*	
		Stress		Stress		Stress	
		MPa	(ksi)	MPa	(ksi)	MPa	(ksi)
5208	-	25.0	(3.63)	27.1	(3.93)	18.6	(2.70)
934	-	23.9	(3.46)	25.9	(3.75)	20.5	(2.97)
F263	-	29.2	(4.23)	23.5	(3.41)	23.5	(3.41)

Interlaminar Tension

Resin	Fiber Volume %	297°K (75°F) dry	
		MPa	(ksi
5208	-	12.3	(1.79)
934	-	7.7	(1.12)
F263	-	8.0	(1.16)

*Wet Conditioned by 168 Hour Immersion in Water at 338.7°K (150°F)

TABLE 19. - SUMMARY OF GRAPHITE SYNTACTIC LAMINATE TEST RESULTS
(LAMINATE ORIENTATION: $(45^\circ/0^\circ/135^\circ/0^\circ/SYN)_s$)

0° Flexure

Resin	Fiber Volume %	297°K (75°F) dry				355.4°K (180°F) wet*			
		Stress		Modulus		Stress		Modulus	
		MPa	(ksi)	GPa	(10^6psi)	MPa	(ksi)	GPa	(10^6psi)
5208	-	845	(122.5)	51.0	(7.4)	826	(119.7)	74.5	(10.8)
934	-	993	(143.9)	56.6	(8.2)	833	(120.8)	73.1	(10.6)
F263	-	793	(114.9)	49.0	(7.1)	718	(104.1)	71.0	(10.3)

0° Short Beam Shear

Resin	Fiber Volume %	297°K (75°F) dry		219.3°K (-65°F) dry		355.4°K (180°F) wet*	
		Stress		Stress		Stress	
		MPa	(ksi)	MPa	(ksi)	MPa	(ksi)
5208	-	19.2	(2.79	24.4	(3.54)	14.8	(2.14)
934	-	21.6	(3.14)	18.6	(2.69)	15.6	(2.26)
F263	-	11.1	(1.61)	10.5	(1.52)	9.0	(1.31)

Interlaminar Tension

Resin	Fiber Volume %	295°K (75°F) dry	
		Stress	
		Mpa	(ksi)
5208	-	15.2	(2.21)
934	-	15.1	(2.19)
F263	-	10.9	(1.58

*Wet Conditioned by 168 Hour Immersion in Water at 338.7°K (150°F)

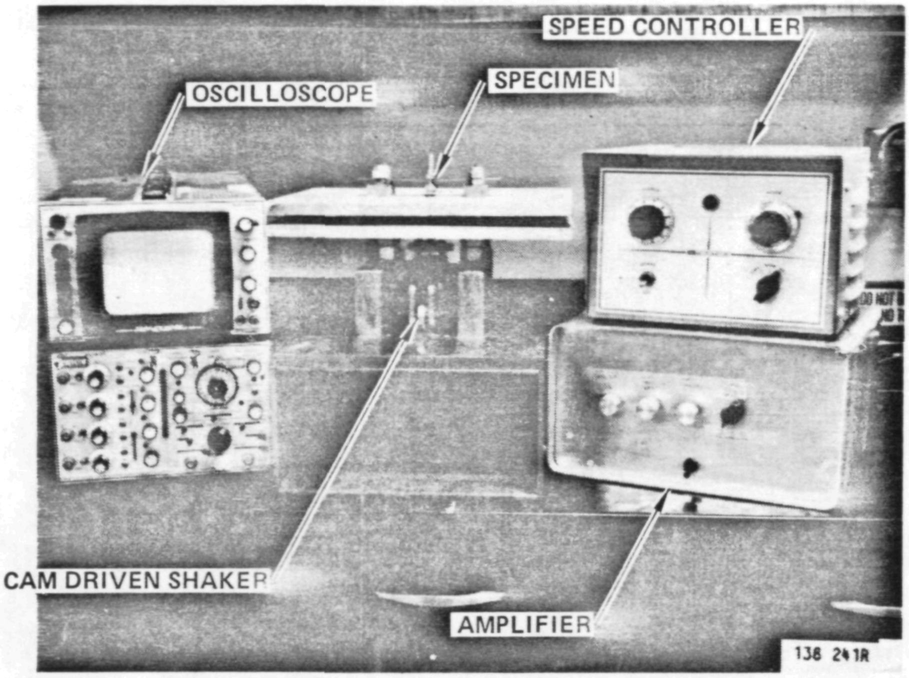


Figure 21.- Dynamic mechanical analysis test equipment.

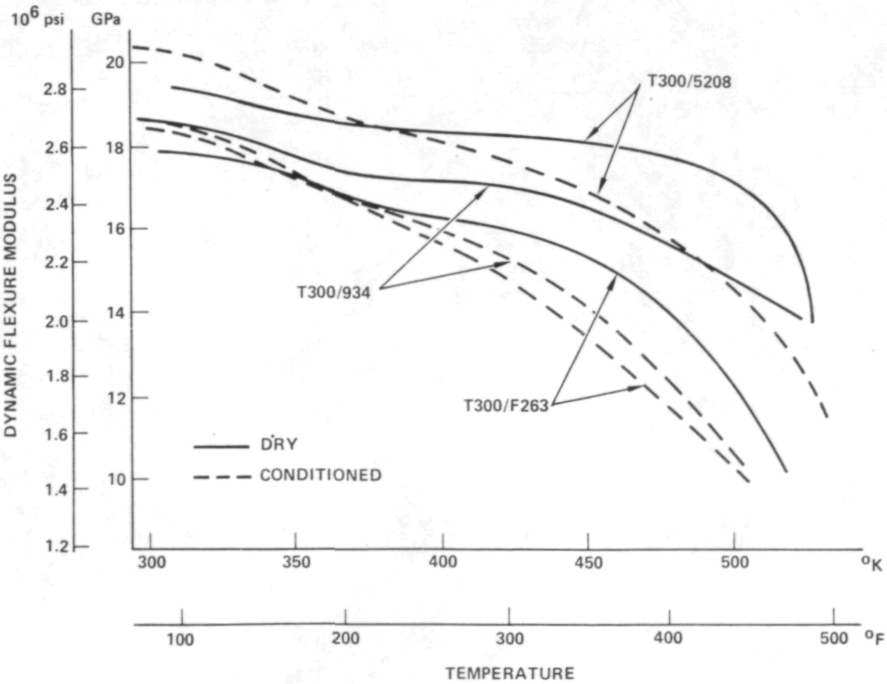


Figure 22.- Dynamic flexure test results.

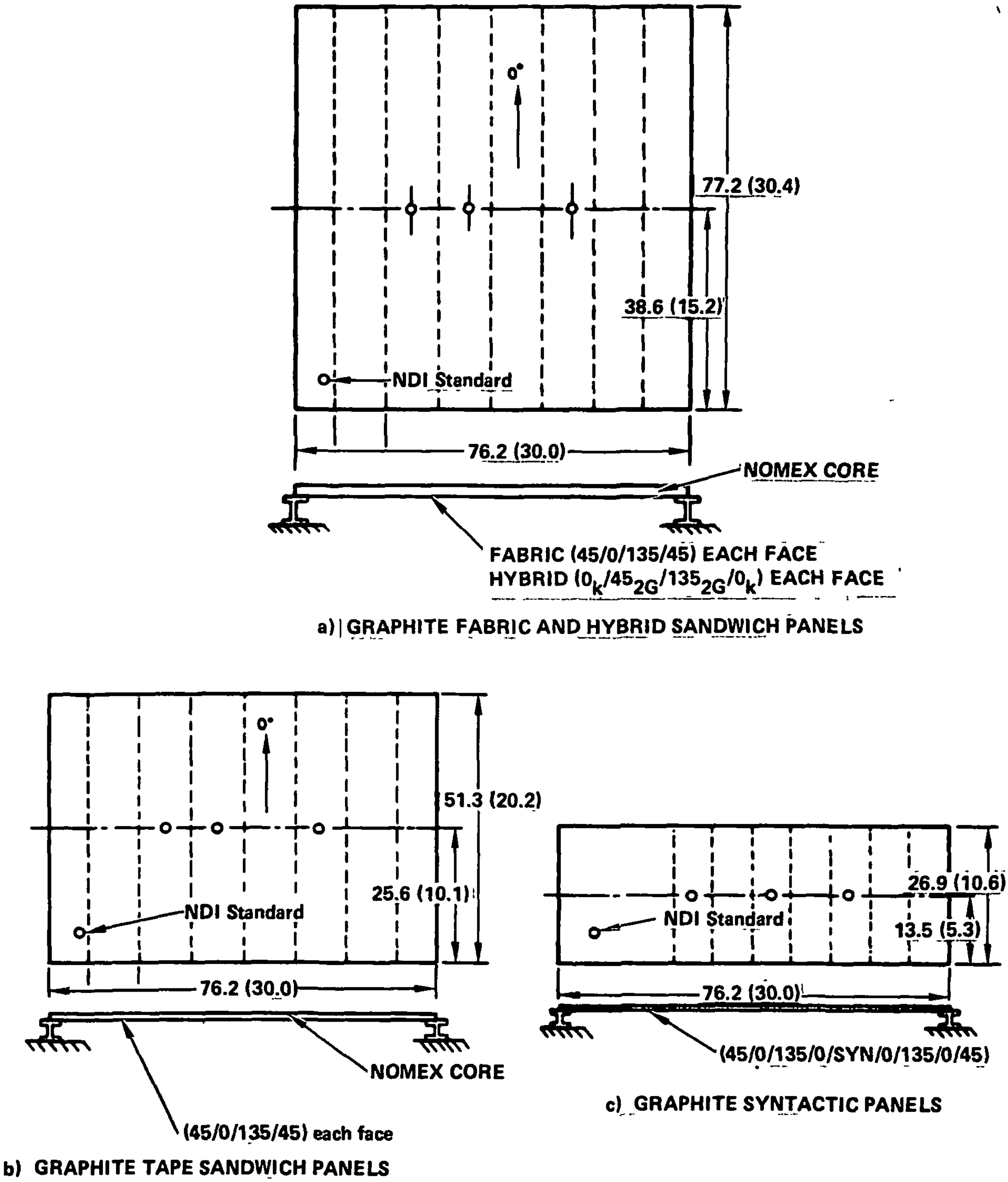


Figure 23. - Impact Test Panels

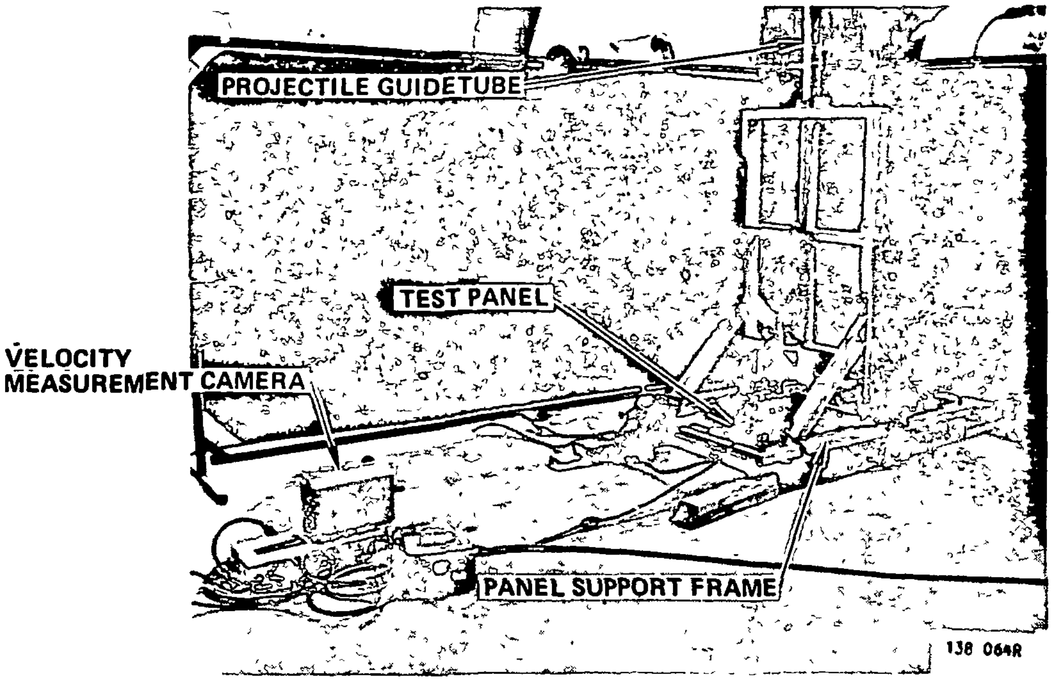


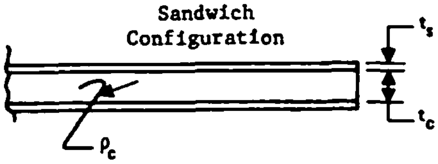
Figure 24. - Setup for panel impact tests.

Following the impact tests each panel was visually and ultrasonically inspected to determine the extent of damage. Typically all of the honeycomb core panels had slight indentations at the point of impact. The ultrasonic C-scans of the panels indicated delaminations of 1.78 cm (0.70 in.) in diameter. Visual inspections of the syntactic core panel revealed no damage. Ultrasonic tests indicated a 1.02 cm (0.40 inch) diameter delamination on each panel at only one impact location, that which was closest to the panel edge support.

Following the inspection each panel was machined into coupons, 7.6 cm (3.0 in.) wide, and tested. The honeycomb core sandwich specimens were tested in flexure with the impacted surface in compression. The syntactic core sandwich coupons were tested in a full-fixity inplane compression test fixture. Three replicates were tested from each panel.

A comparison of the measured compressive strength of the test panels before and after impact is shown in table 20. The results indicate a greater proportional drop in strength occurred on the graphite faced honeycomb and syntactic panels than the panels faced with Kevlar 49, or a hybrid laminate. No significant difference in impact resistance of the three candidate resins was evident from the test data.

TABLE 20. - SUMMARY OF IMPACT TEST RESULTS

Sandwich Configuration	Resin	Not Impacted Stress 2 MPa	(ksi)	Impacted 1 Stress 2 MPa	(ksi)
					
Graphite Tape/Nomex Core Layup. $(0^o/45^o{}_2/90^o/135^o{}_2)$	5208	271.1	(39 3)	263 5	(38.2)
t_s = 0.076 cm (0.030 in.) t_c = 1.57 cm (0.62 in.)	934	349.0	(50.6)	258.0	(37.4)
ρ_c = 0.165 kg/m^3 (4.0 lb/ft^3)	F263	321.4	(46.6)	227.6	(33.0)
Kevlar 49 Fabric/Nomex Core Layup. $(45^o/0^o/135^o/45^o)$	5208	169.0	(24.5	145.5	(21.1)
t_s = 0.102 cm (0.040 in.) t_c = 1.57 cm (0.62 in.)	934	155.9	(22.6)	144.2	(20.9)
ρ_c = 0.165 kg/m^3 (4.0 lb/ft^3)	F263	166.9	(24.2)	148.3	(21 5)
Graphite-Kevlar 49 Hybrid/Nomex Core Layup $(0^o{}_k/45^o{}_{2G}/135^o{}_{2G}/0^o{}_k)$	5208	182.1	(26.4)	184.8	(26.8)
t_s = 0.102 cm (0.040 in.) t_c = 1.57 cm (0.62 in.)	934	177.9	(25.8)	177.9	(25.8)
ρ_c = 0.165 kg/m^3 (4.0 lb/ft^3)	F263	182.1	(26.4)	167.6	(24.3)
Graphite Tape/Syntactic Core Layup: $(45^o/0^o/135^o/0^o)$	5208	493.2	(71.5)	404.9 3 284.9 4	(58.7) 3 (41.3) 4
t_s = 0.051 cm (0.020 in.) t_c = 0.102 cm (0.040 in.)	934	498.7	(72.3)	386.3 3 310.4 4	(56.0) 3 (45.0) 4
ρ_c = 1.78 kg/m^3 (43.2 lb/ft^3)	F263	382.8	(55.5)	376.6 3 271.8 4	(54.6) 3 (39.4) 4

1 Impacted at 2.71J (2 ft-lb) by 2.54 cm (1.0 in.) diameter spherically ended steel rod

2 Compression, sandwich flexure for Honeycomb core specimens full fixity inplane compression for syntactic core specimens

3 Average of two tests on specimens which showed no ultrasonic indications

4 Test on specimen which showed an ultrasonic indication of approximately 1.02 cm (0.40 in) diameter

It should be noted that the impact energy used for these test panels was approximately five times greater than the impact criteria established for the ACA (see page 7). A higher value of impact energy was used for these tests to assure that the laminates would be damaged by the impact. During Task II of the aileron program additional impact tests will be conducted to verify the ability of the selected materials and design concept to meet the impact design criteria.

Producibility screening tests. - The producibility aspects of the three candidate resin systems were evaluated by Avco. Flat plates, sections of the rib configuration, and sandwich plates were fabricated. During fabrication, tack, backing paper adhesion, bleed characteristics, drilling and sawing characteristics, and drapability were evaluated. The results of this evaluation, shown in table 21, do not indicate a clear cut producibility superiority of one system over the other two.

Coupons for physical and mechanical property tests were machined from each of the parts described in table 21. Data from fiber volume measurements, short beam shear, flexure and flatwise tensile tests is presented in table 22. In general, this data indicated that the 5208 system had the highest mechanical properties.

In the evaluation of qualitative data no one material was significantly better than the others. However, the following observations were made:

1. Fabric layup is easier than tape layup.

2. All specimens were preplied prior to layup and drapability is better with fabric than tape.

3. 121.92 cm (48 in.) fabric uses less labor to cut the composite than 30.48 cm (12 in.) tape.

4. During layup, errors are more easily correctable with fabric than with tape.

5. Fabric materials with same resin content exhibit handling properties of tape materials of less resin content; this is a result of the method of resin impregnation. This condition is more pronounced with older materials.

6. The surface finish of a part made with tape is better than one made with fabric.

7. Syntactic sandwich panels are much easier to layup than honeycomb sandwich panels.

8. The Kevlar panels are more difficult to cut and machine than graphite.

TABLE 21. - PRODUCIBILITY SCREENING - QUALITATIVE TEST RESULTS

NO.	Resin Type	Material	Construction	Size & Type	General Qualitative Analysis					
					Tack	Backing Paper Adh	Bleed	Drill	Saw	Drape
P1 P2 P3	5208 934 263	Gr Tape	16 Ply $(45^{\circ}, 90^{\circ}, 135^{\circ}, 0^{\circ})_s$	60 96 cm (24 in) x 91 44 cm (36 in) Plate SOLID GR	G F G	G F G	P P P	F F F	G G G	- F F
P4	5208	GR Tape Syntactic	4 Ply, 1 Ply, 4 Ply $(45^{\circ}, 90^{\circ}, 135^{\circ}, 0^{\circ})_s$	60 96 cm (24 in) x 91 44 cm (36 in) Plate GR, SYN, GR	G	G	F	F	G	-
R1	5208	GR Tape	8 Ply $(45^{\circ}, 90^{\circ}, 135^{\circ}, 0^{\circ})_s$	30.48 cm (12 in) Rib Section Solid GR	-	G	-	-	-	F
R2 R3 R4	5208 934 263	24 x 23 GR Fabric 8HS	3 Ply $(45^{\circ}, 0^{\circ}, 135^{\circ})$	30.48 cm (12 in) Rib Section Solid GR	F F F	- - -	- - -	- - -	- - -	G G G
S1 S2 S3	5208 934 263	K49 Nomex	Nomex Sand 4 Ply Face SH $(45^{\circ}, 0^{\circ}, 135^{\circ}, 45^{\circ})_s$	60.96 cm (24 in) x 91 44 cm (36 in) Plate	P F P	P G P	- - -	- - -	- - -	F G P

LEGEND:
C - Complete
G - Good
F - Fair
P - Poor
X - Required
\- - Not Required

TABLE 22. - PRODUCIBILITY SCREENING - QUANTITATIVE TEST RESULTS

Candidate No.	Material	Fiber Volume (1)	Short Beam Shear		Flexure (2)	
		%	M Pa	psi	M Pa	psi
P1	5208 Tape (NARMCO)	68.40	60.4	8754	610	88415
P2	934 Tape (FIBERITE)	69.17	51.7	7499	604	87551
P3	263 Tape (HEXCEL)	62.33	48.5	7025	548	79453
P4	5208 Tape & ADX-819 Syn. (Hysol)	54.17	30.4	4410	449	65140
R1	5208 Tape	73.12				
R2	5208 Fabric	66.67				
R3	934 Fabric	70.00				
R4	263 Fabric	69.17				

Candidate No.	Material	Flatwise Tensile (3)	
		M Pa	psi
S1	5208 - K49 - NOMEX	2.58	374.4
S2	934 - K49 - NOMEX	2.56	370.8
S3	263 - K49 - NOMEX	2.46	356.0

(1) This number includes the weight of the microballoons within the syntactic epoxy core.
(2) Tension failure in tension fibers all specimens.
(3) Approximately 50% each core and skin failure, no bond line failures.

9. The 285 Kevlar weave has good drapability on double curved surfaces. The corners on the sandwich panels can be formed without slitting and lapping the corners.

In summary, the evaluation of materials to date indicates that fabric with Narmco 5208 resin is superior.

As part of the producibility screening tests, Avco has made a preliminary evaluation of tooling techniques for the channel section ribs to be used for the aileron assembly. Graphite fabric ribs were made using both male and female tooling. Conventional bagging approaches and formed rubber bags (see figures 25 and 26) were used on both tools. In addition, several ribs were made in a female tool using a formed rubber block in conjunction with a conventional vacuum bag.

Parts made in a female tool using a conventional vacuum bag or a formed rubber bag showed evidence of bridging and porosity in the radii of the rib. Parts made in the male tool showed no evidence of bridging in the radii; however, the parts did have large dimensional variance. The dimensional problems using a male tool appear to be correctable by tool development; however, the accumulation of tolerances to the outside mold lines for the ribs and spar could be a problem. Ribs fabricated using the female tool in conjunction with the rubber block and conventional bagging showed no evidence of bridging or porosity in the radii.

A preliminary evaluation of the tooling techniques investigated indicates that the female tool using a rubber block and conventional bag is the best method for fabricating the ribs and spar of the aileron. Additional process development activities will be conducted during Task II.

Selected materials. - Data from the structural screening tests and other factors entered into the selection of the resin system. These factors included the results of the producibility screening tests performed at Avco. Additional factors were available data base and processing history at Lockheed and availability of the system in pre-plied tape form, which proved to be an essential factor in reducing production costs.

Consideration of all this information led to the decision to use Narmco's 5208 prepreg system, with the reinforcement forms of 0.019 cm (7.5 mil) unidirectional tape and bidirectional 0.033 cm (13 mil), satin weave graphite fabric. The basic reasons for this selection are:

- Superior hot, wet properties of 5208
- Equivalent processability of 5208 to other candidate systems
- Availability of 5208 allowables data from the Advanced Composite Vertical Fin (ACVF) Program, NASA Contract NAS1-14000
- Development of processing experience at Lockheed with 5208 from the ACVF program

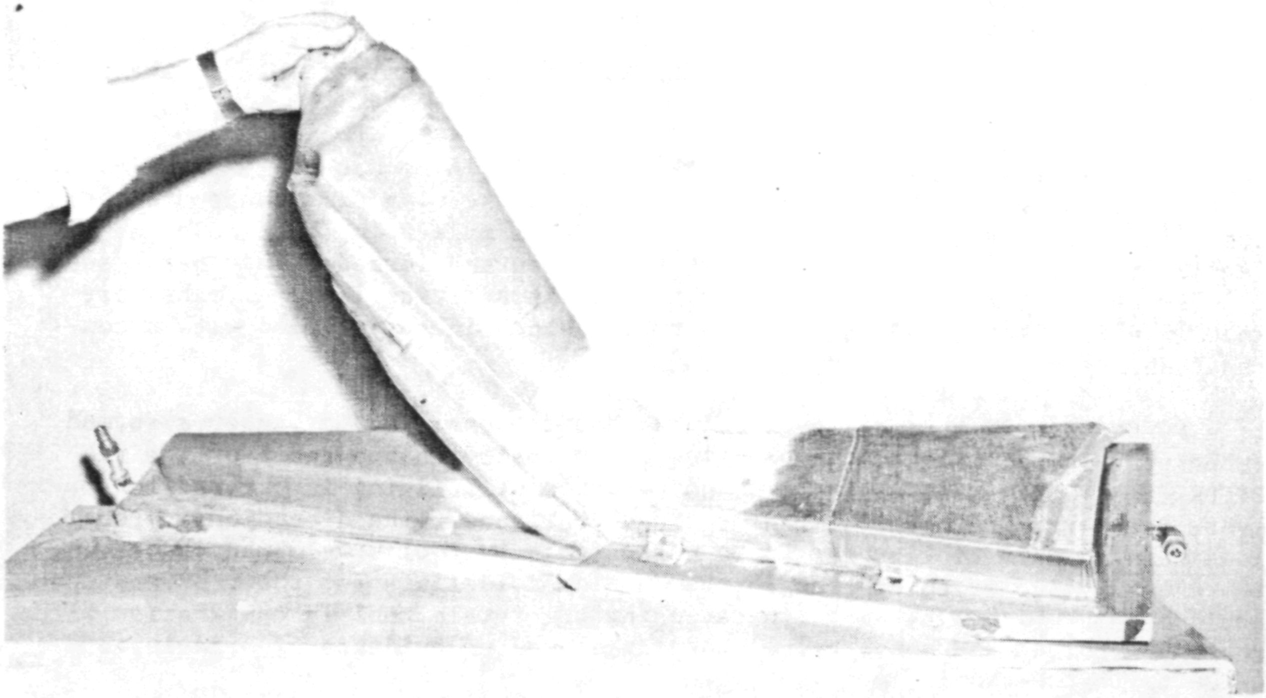


Figure 25. - Male tool and formed rubber bag.

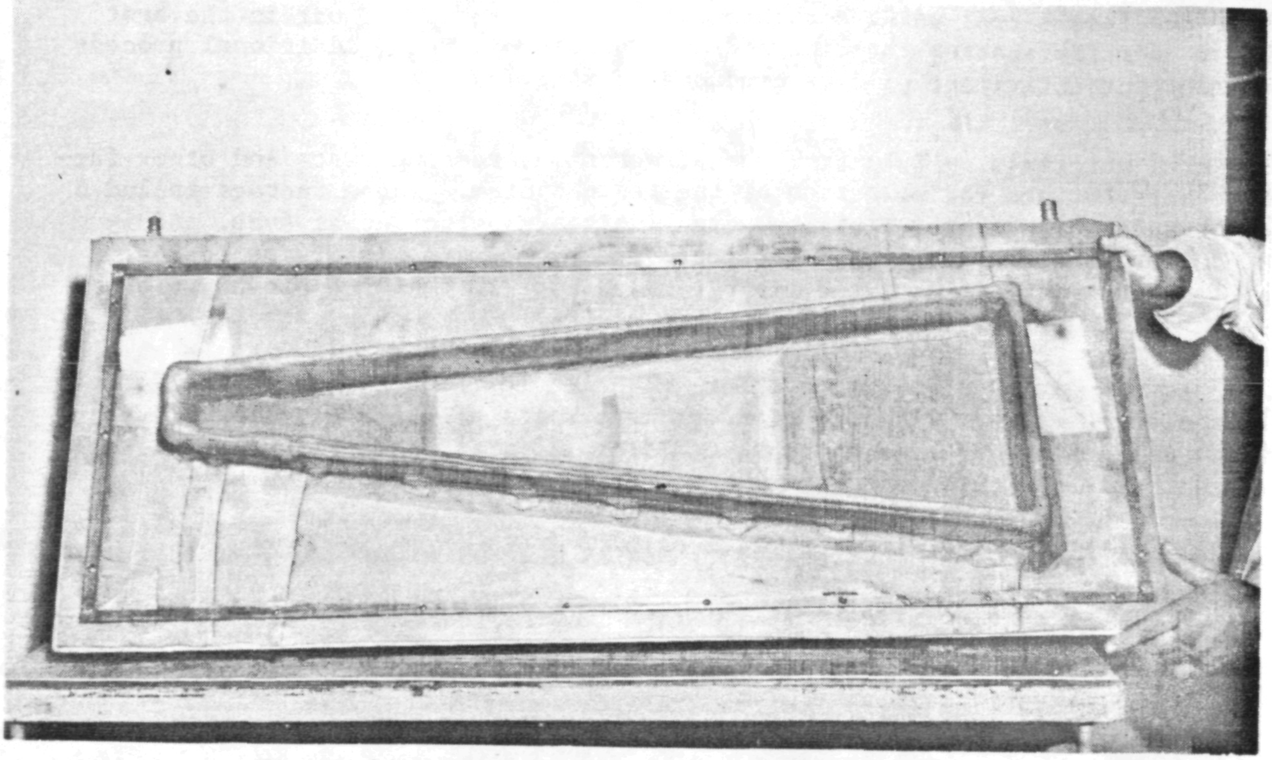


Figure 26. - Female tool and formed rubber bag.

- Narmco's position as the only one of the candidate suppliers to make a firm commitment for development of preplying capability.

CONCLUSIONS

Two primary activities were completed during Task I, design assessment and material evaluation.

The objective of the design assessment subtask was to select a design concept for the ACA with the greatest potential for meeting the program objectives. The approach used for this activity was to define the design criteria, develop alternate designs, evaluate the alternatives against the cost and weight objectives, and select the best alternative.

Design and evaluation of alternate concepts for the major subcomponents of the ACA was completed. From this array of subcomponents aileron assemblies were formulated and evaluated. Based on these analyses a multirib assembly with graphite tape/syntactic core covers, a graphite tape front spar, and graphite fabric ribs was selected for development in the remainder of the ACA program. A weight savings of 29.1% (40.8 pounds per aileron) is currently being predicted for the ACA. Engineering cost analyses indicate that the production cost of the ACA will be 7.3% less than the current aluminum aileron.

Material evaluation activities consisted of an initial qualitative screening of candidate prepregs. The qualitative screening study also identified three filamentary reinforcement types as having potential application to the ACA design. These were unidirectional graphite tape, graphite fabric, and Kevlar 49 fabric reinforcements. Three resin systems were selected for inclusion in the quantitative screening tests: Narmco 5208, Fiberite 934, and Hexcel F-263. The quantitative screening consisted of structural screening tests performed at Lockheed and producibility screening tests performed at AVCO.

Fabrication, machining, and testing of the material evaluation specimens for the resin screening program was completed at Lockheed-California Company and Avco. These test results lead to the selection of Narmco 5208 resin for the ACA.

REFERENCES

1. James, A.M.; Fogg, L.D.; and VanHamersveld, J.A.: Design of Advanced Composite Ailerons on Transport Aircraft; Summary Report. NASA CR-132637, 1975.

2. James, A.M.; and Fogg, L.D.: Design of Advanced Composite Ailerons on Transport Aircraft; Design Report. NASA CR-132638, 1975.

3. James, A.M.; and VanHamersveld, J.A.: Design of Advanced Composite Ailerons on Transport Aircraft; Production and Flight Service Evaluation Plan. NASA CR-132639, 1975.

1 REPORT NO NASA CR-145370	2 GOVERNMENT ACCESSION NO	3 RECIPIENT'S CATALOG NO
4 TITLE AND SUBTITLE Advanced Composite Aileron For L-1011 Transport Aircraft: Task I - Final Report		5 REPORT DATE April 1978
		6. PERFORMING ORG CODE
7 AUTHOR(S) C. F. Griffin, L. D. Fogg, R. L. Stone, E. G. Dunning		8. PERFORMING ORG REPORT NO LR 28568
9 PERFORMING ORGANIZATION NAME AND ADDRESS LOCKHEED-CALIFORNIA COMPANY P O BOX 551 BURBANK, CALIFORNIA 91520		10. WORK UNIT NO
		11 CONTRACT OR GRANT NO NAS 1-15069
12 SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Langley Research Center Hampton, Virginia 23665		13 TYPE OF REPORT AND PERIOD COVERED 19 September '77 to 24 March 1978
		14 SPONSORING AGENCY CODE
15 SUPPLEMENTARY NOTES		

16 ABSTRACT

The activities documented in this report are associated with Task I of the Advanced Composite Aileron (ACA) program. These activities include: design assessment, material evaluation, and program plans.

Structural design and maintainability criteria were established. Using these documents as a guideline, a variety of configurations and materials were evaluated for each of the major subcomponents. From this array of subcomponent designs, several aileron assemblies were formulated and analyzed. The selected design is a multirib configuration with sheet skin covers mechanically fastened to channel section ribs and spars.

Qualitative analysis of currently available composite material systems led to the selection of three candidate materials. Comparative structural tests were conducted on the candidate materials to measure the effects of environment and impact damage on mechanical property retention. In addition, each system was evaluated for producibility characteristics. From these tests, Thornel 300/5208 unidirectional tape was selected for the front spar and covers, and Thornel 300 fabric/5208 was chosen for the ribs.

Program plans were established for materials evaluation and selection, defining the ancillary tests required for materials and concept verification, defining the approach to be followed in satisfying the Federal Aviation Administration (FAA) requirements for certification, and establishing the procedure for preparation and implementation of a structural integrity program.

17 KEY WORDS (SUGGESTED BY AUTHOR(S))	18. DISTRIBUTION STATEMENT
Composites, Materials, Secondary Structure Design, Testing, Transport Aircraft, Graphite Epoxy	FEDD Distribution

19 SECURITY CLASSIF. (OF THIS REPORT)	20 SECURITY CLASSIF. (OF THIS PAGE)	21 NO OF PAGES	22 PRICE*
Unclassified	Unclassified	56	$4.50

Available: NASA's Industrial Applications Centers

1200 6 APR 1978

DOUGLAS AIRCRAFT COMPANY

3855 Lakewood Boulevard Long Beach California 90846 (213) 593 5511

MCDONNELL DOUGLAS
CORPORATION